MEMS Programs at DARPA

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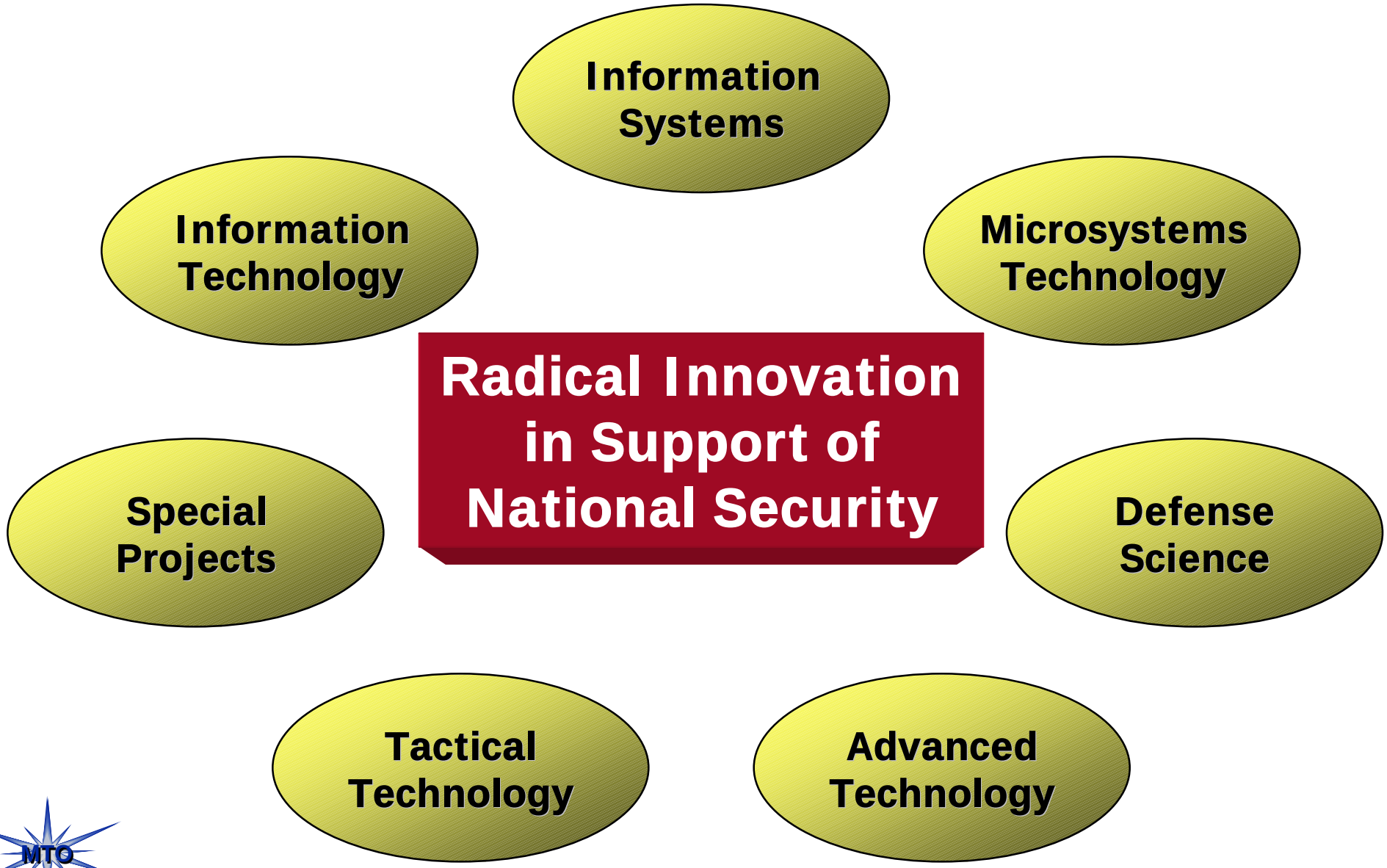
Outline

- Introduction
- Current Thrusts
- New Programs
- Conclusion

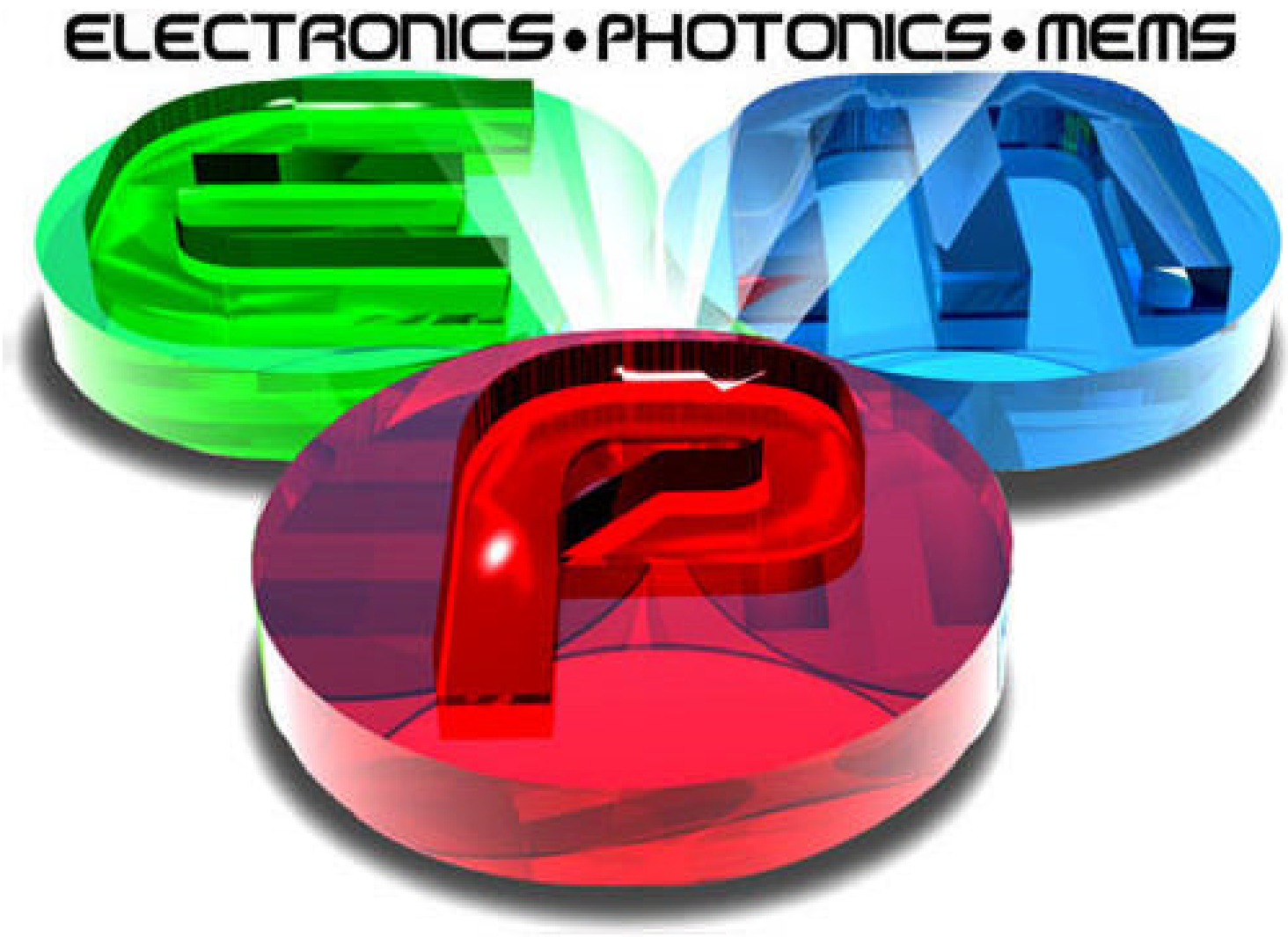
DARPA Mission



Strategy

- Find and exploit externally generated ideas
- Invest in high-risk, high-focus projects
- Promote fair and healthy competition

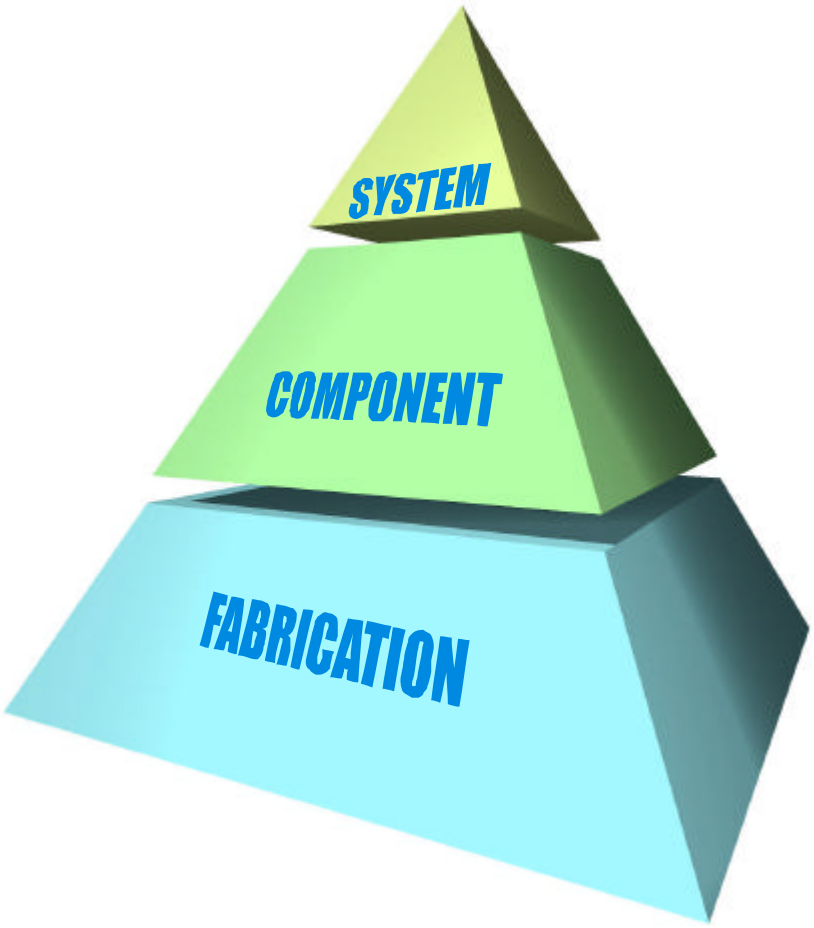
Microsystems Technology Office



Technology for Chip-Level Integration of E. P. M.

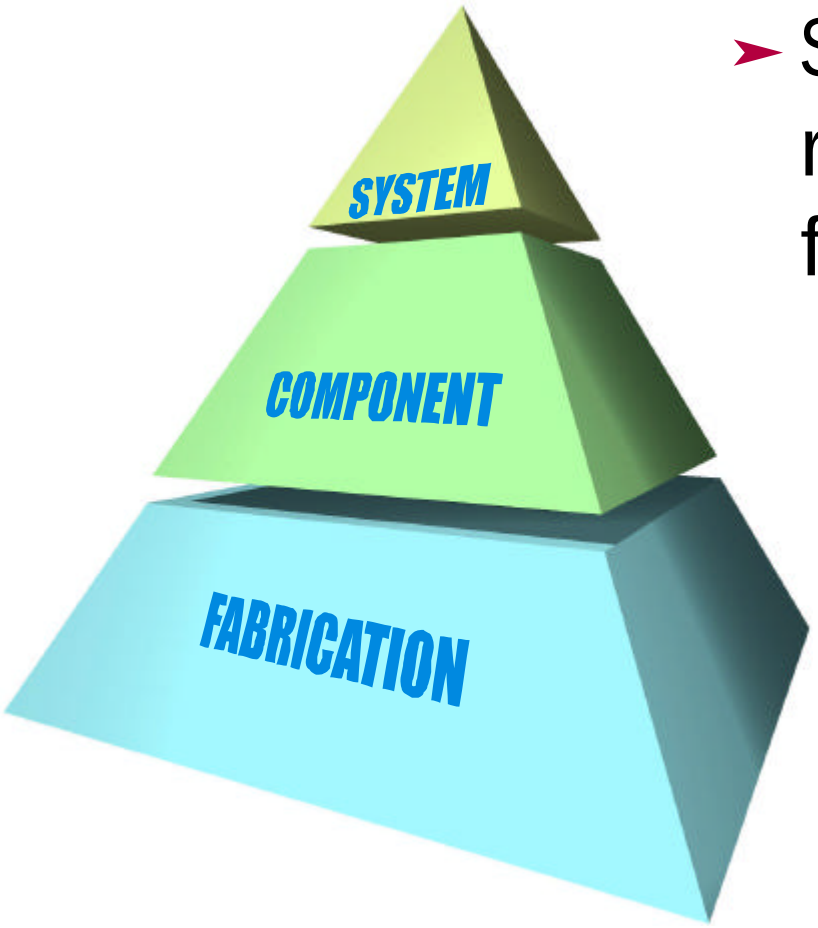
MEMS – A Core Technology

- Micro-Electro-Mechanical Systems (MEMS) is a core technology that:
  - Leverages IC fabrication technology
  - Builds ultra-miniaturized components
  - Enables radical new system applications



MEMS – A Core Technology

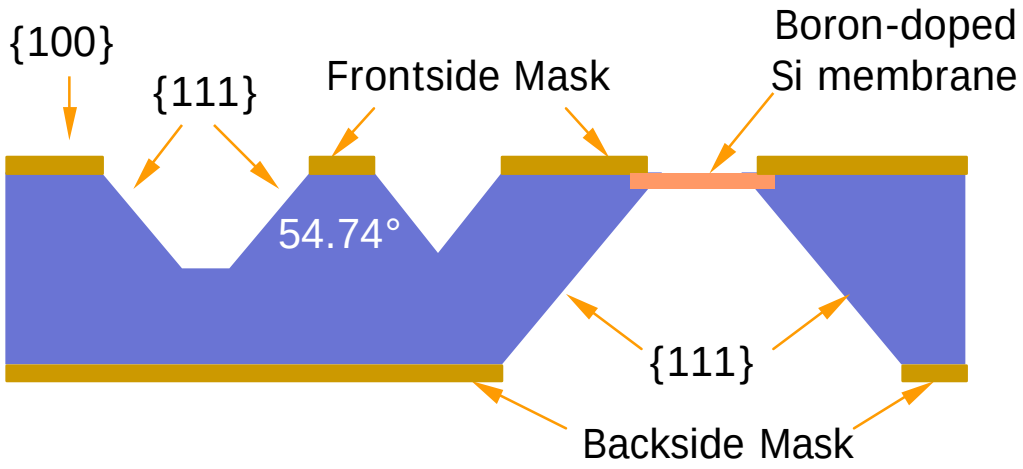
- Future of MEMS:
  - System needs will define research in devices and fabrication

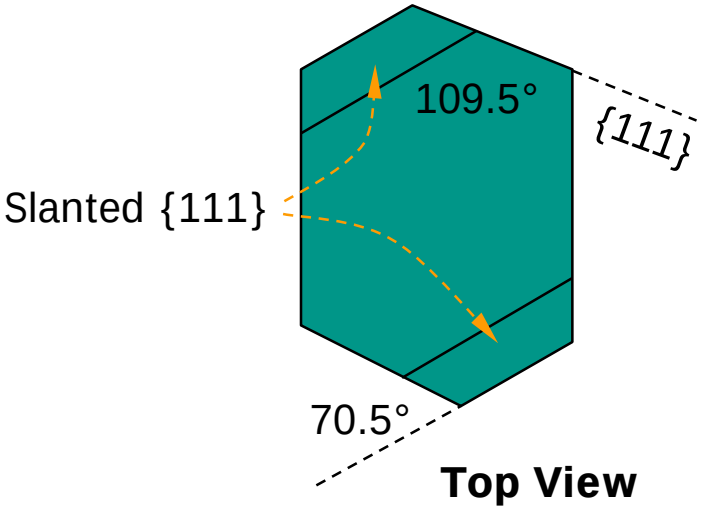


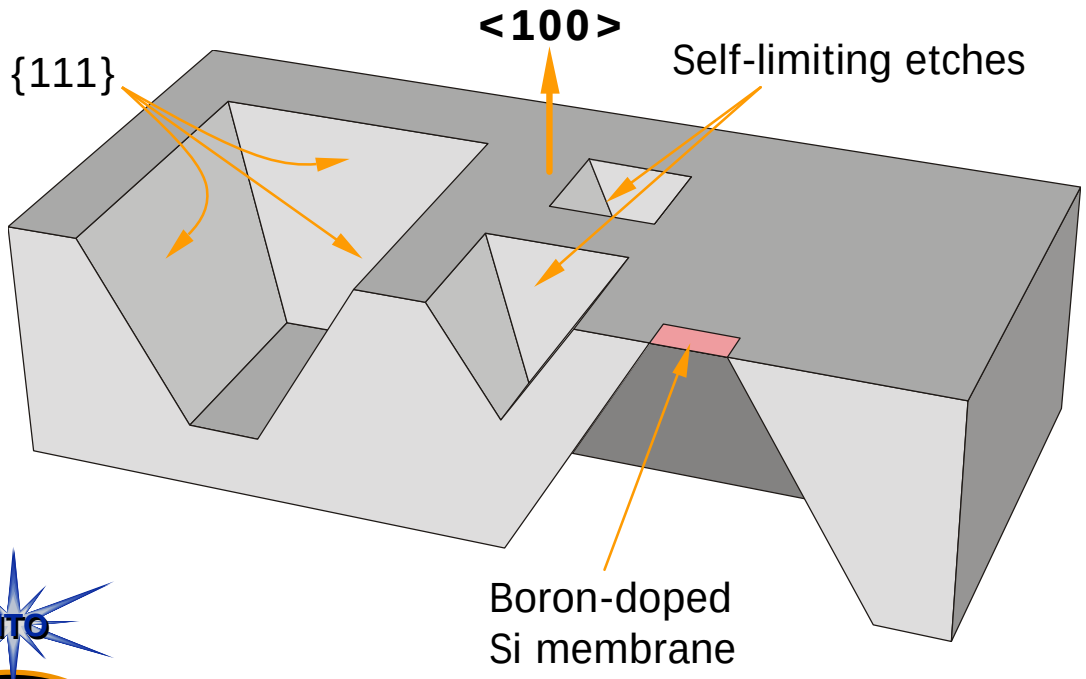
MEMS Technologies

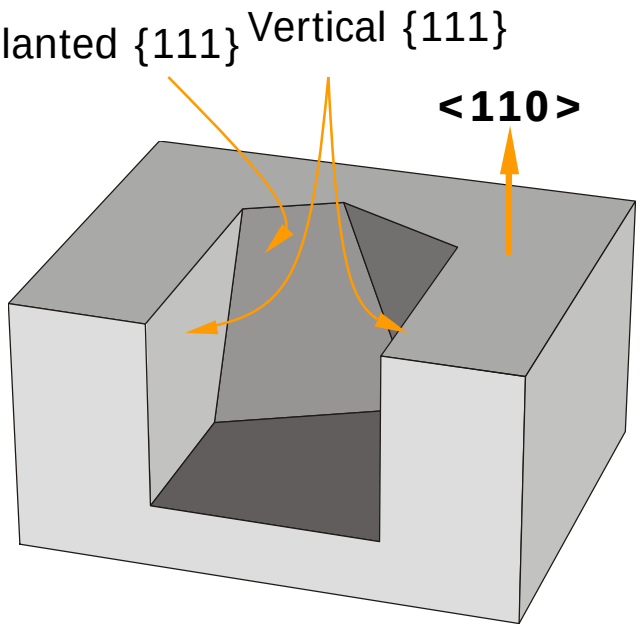
- Bulk Micromachining
- Surface Micromachining
- Wafer Bonding
- LIGA/SLIGA and LIGA-Like
- Others
  - Micro EDM
  - 3-D Lithography
  - Laser Micromachining

Anisotropic Wet Etching of Silicon

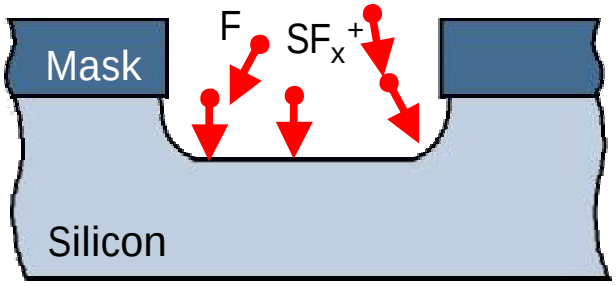




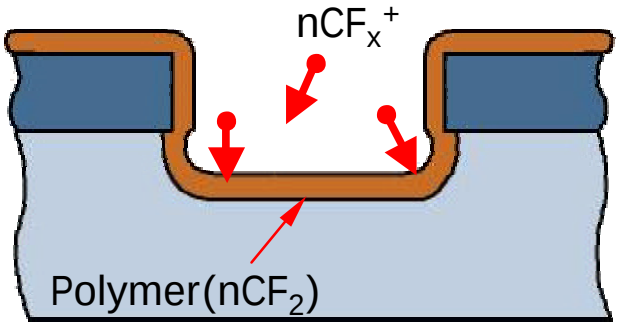




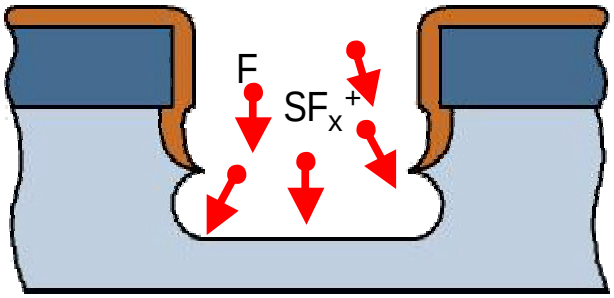
Deep Reactive Ion Etching (DRIE)



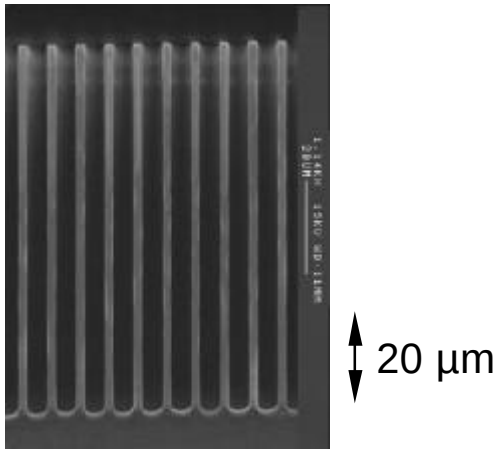
Etch



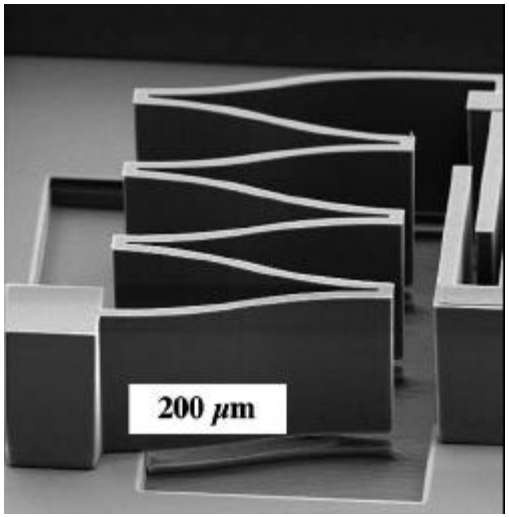
Deposit Polymer



Etch

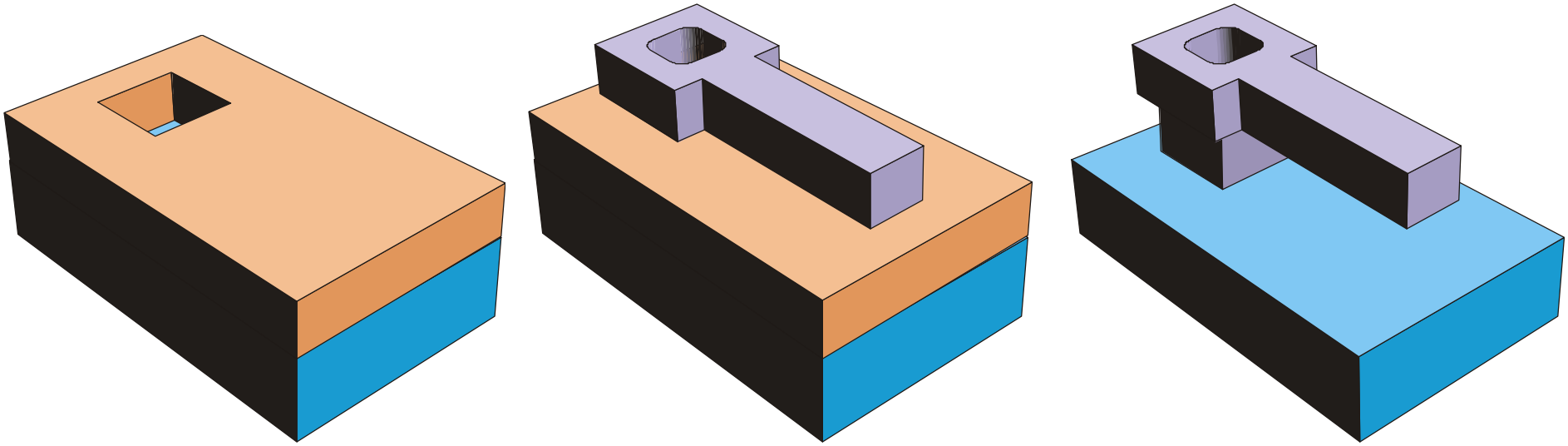


Trenches - *Surface Technology Systems*

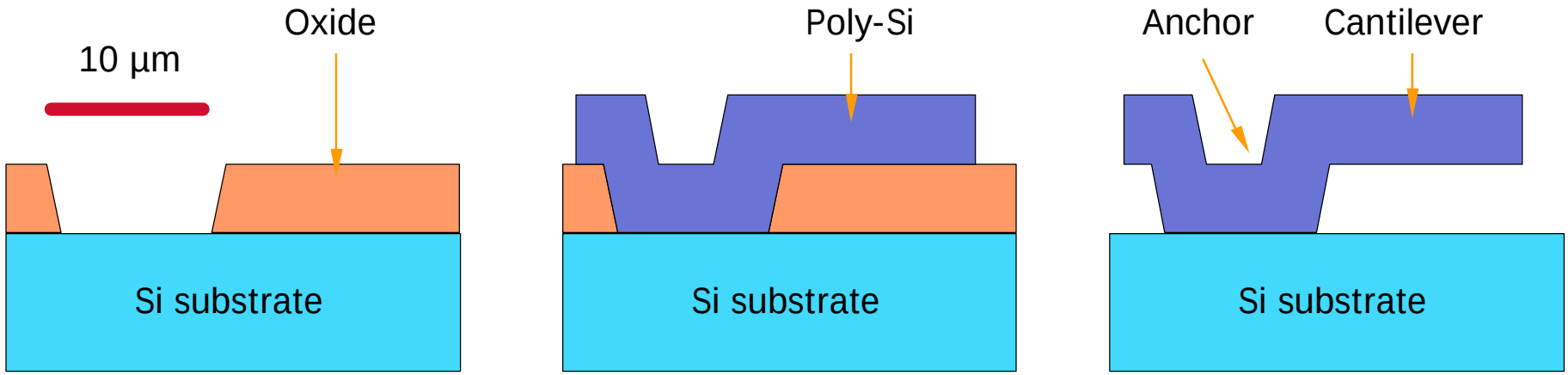


Spring - Klaassen, *et al,* 1995

Surface Micromachining

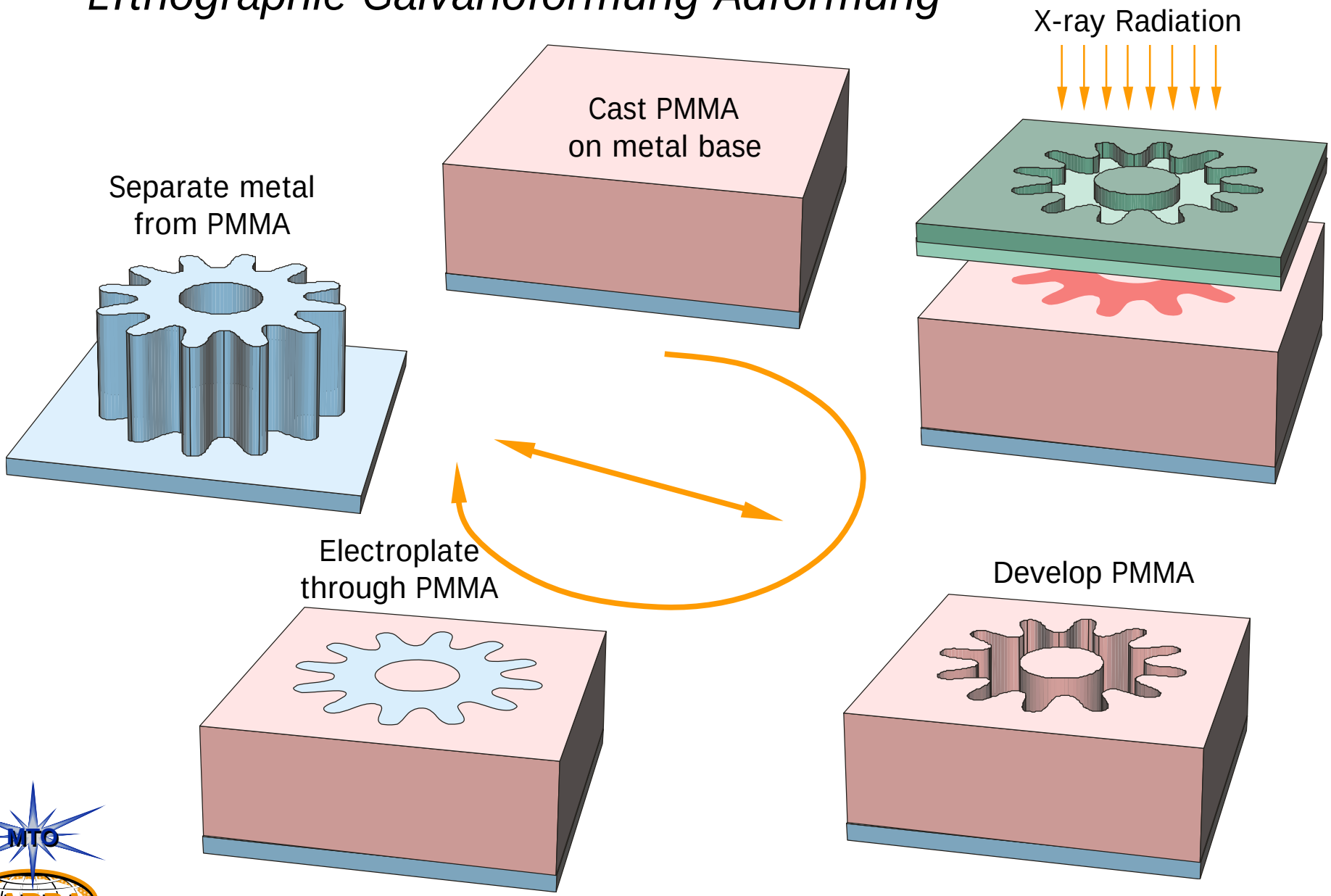


Deposit & pattern oxide ***Deposit & pattern poly*** ***Sacrificial etch***

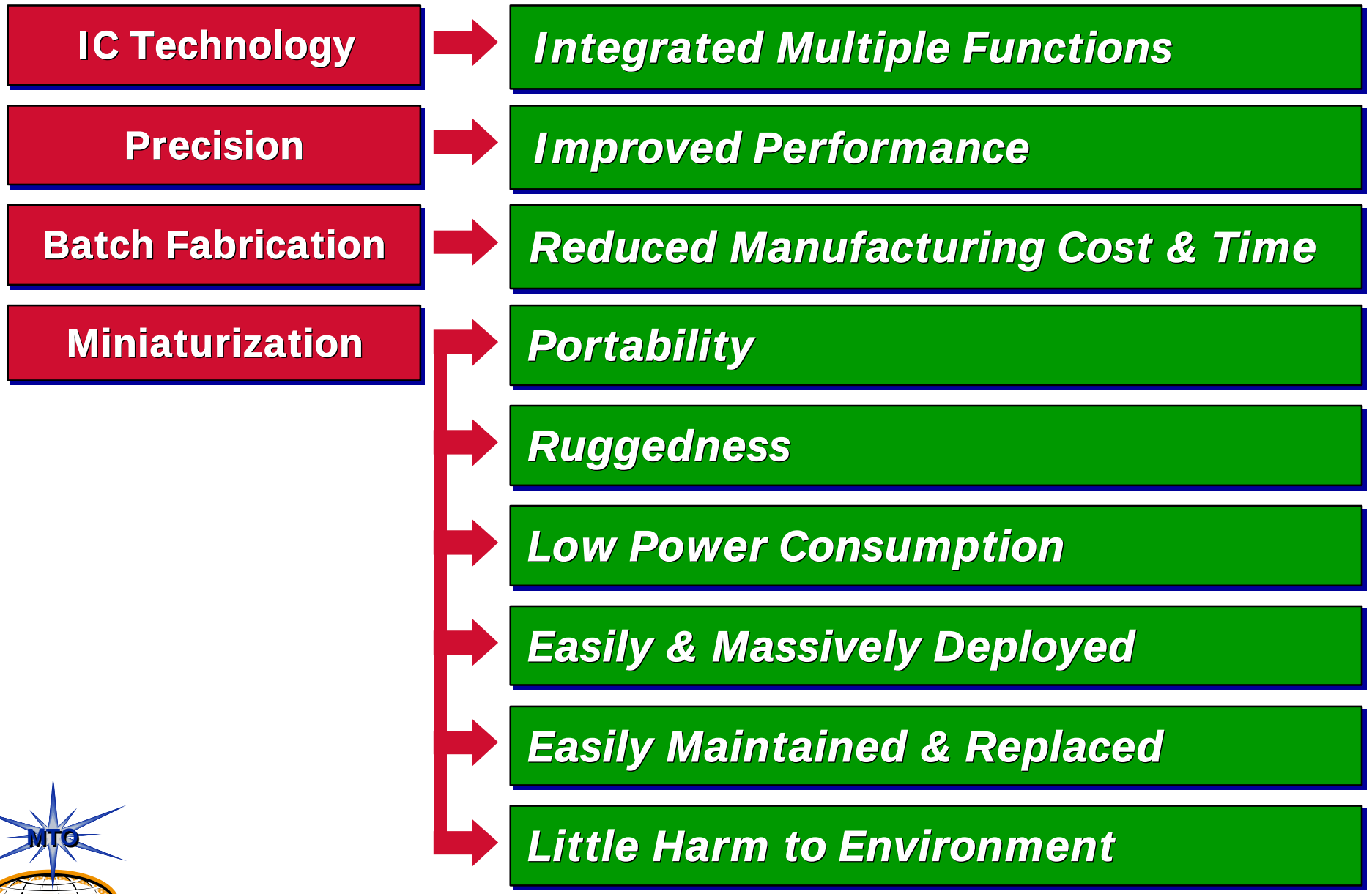


LIGA Process

LIthographie Galvanoformung Adformung



Advantages of MEMS



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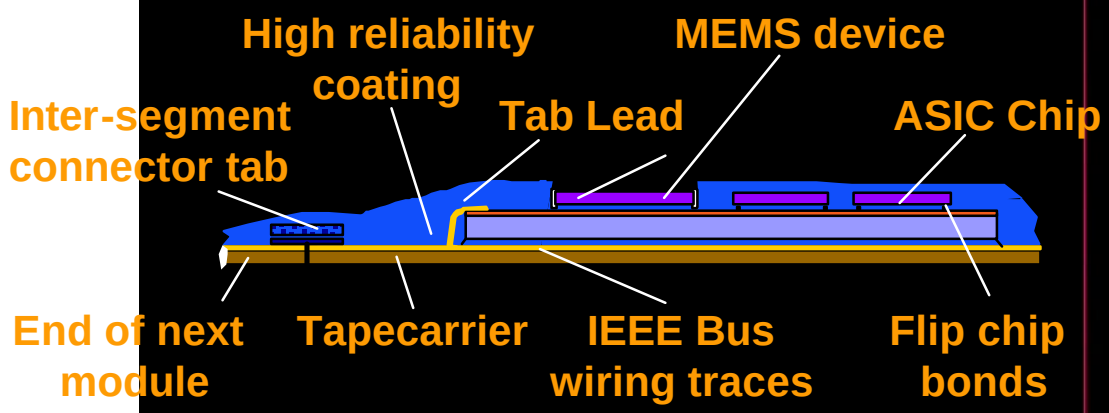
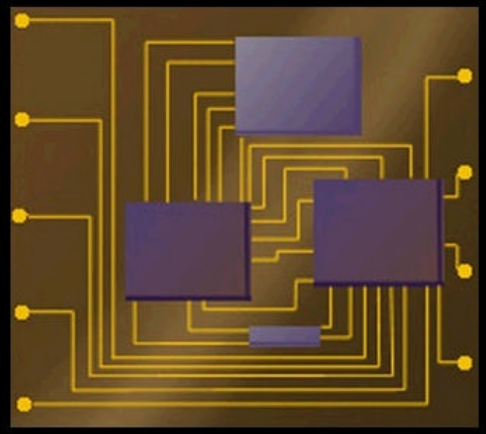
Pressure Sensor Belt on Jet Planes

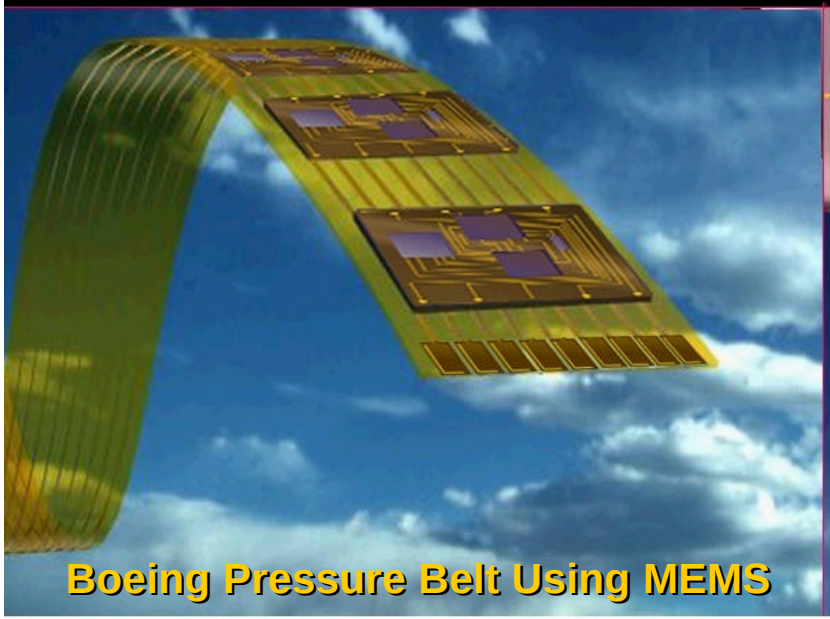
Pressure Belt Cross Section



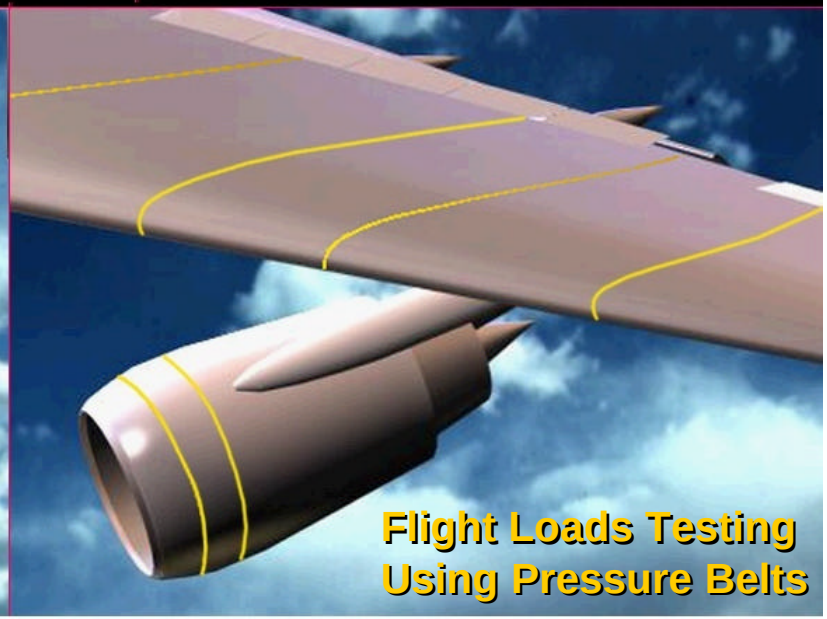
(Vertical scale enlarged for illustration only)

MEMS Sensor Integrated on an MCM with Embedded Passives



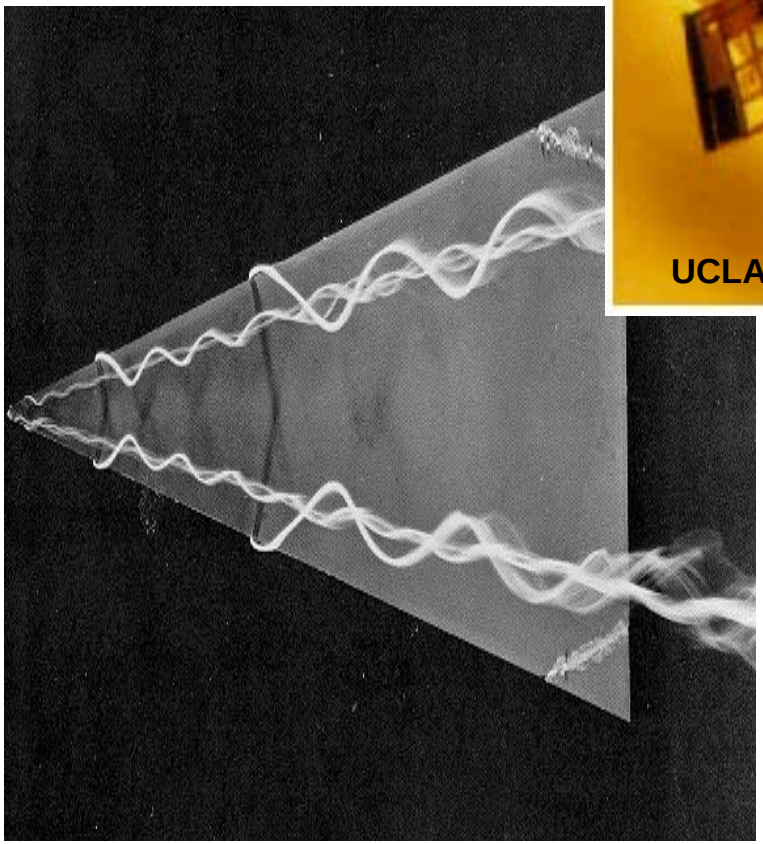


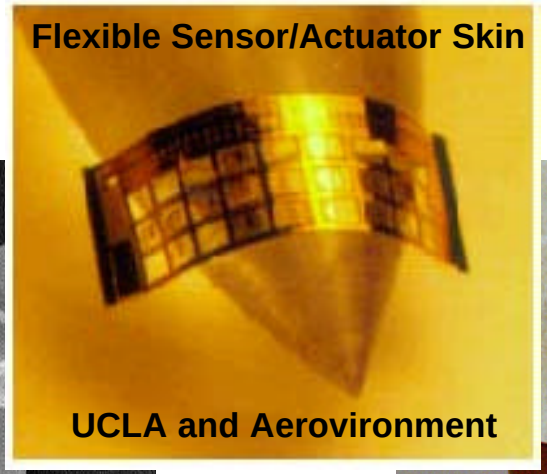
Boeing Pressure Belt Using MEMS



Flight Loads Testing Using Pressure Belts

MEMS Actuators for Aero Control

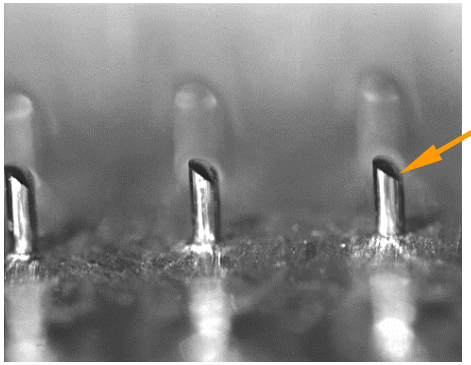




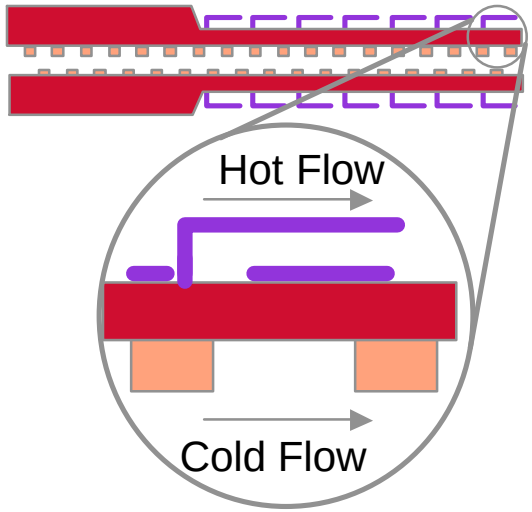
MEMS Actuator Array on the Leading Edge of Wing of 1/7 Scale Mirage III Fighter

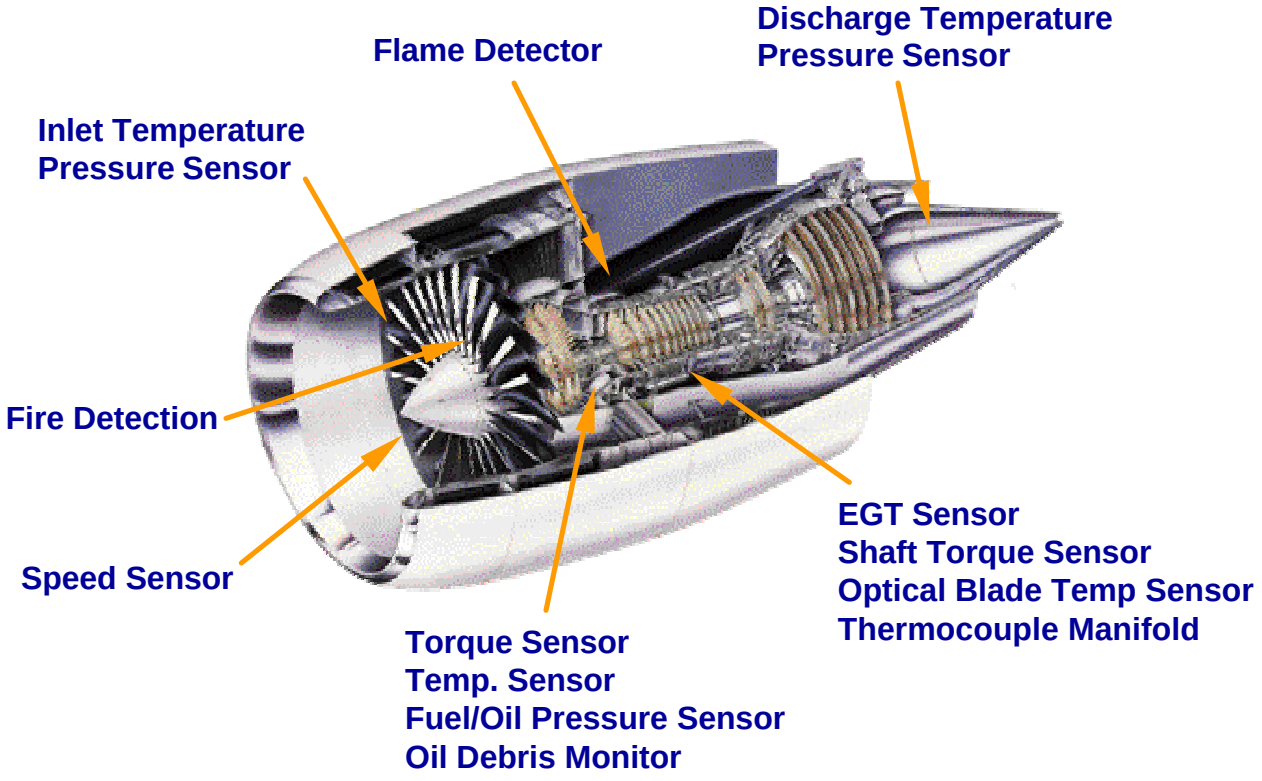
UCLA and Aerovironment

MEMS-Enhanced Jet Engine



Micro heat fins of nickel rods 150 µm diameter, 500 µm tall, spaced on 1.0 mm centers on a 1.7 cm diameter rod. (LSU)

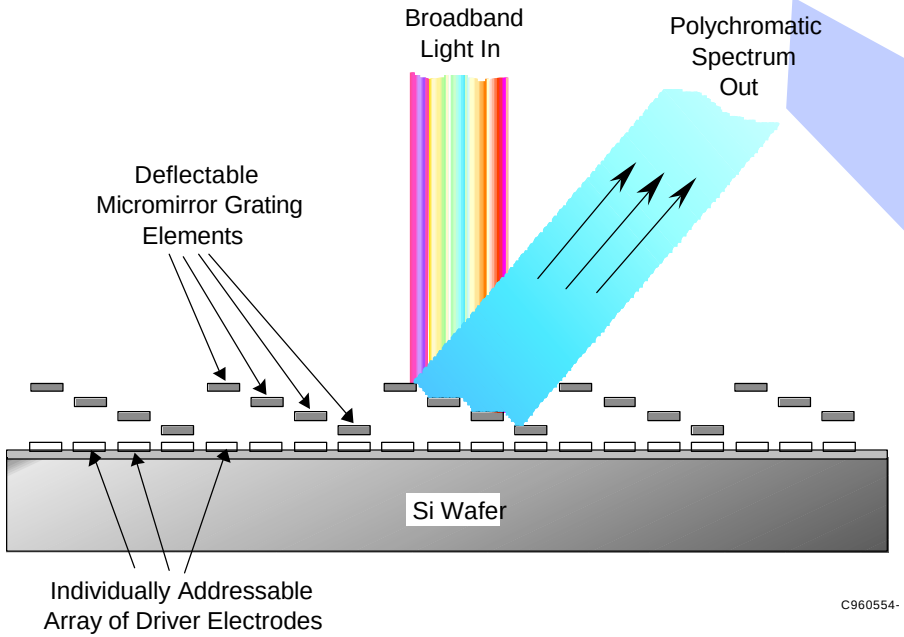




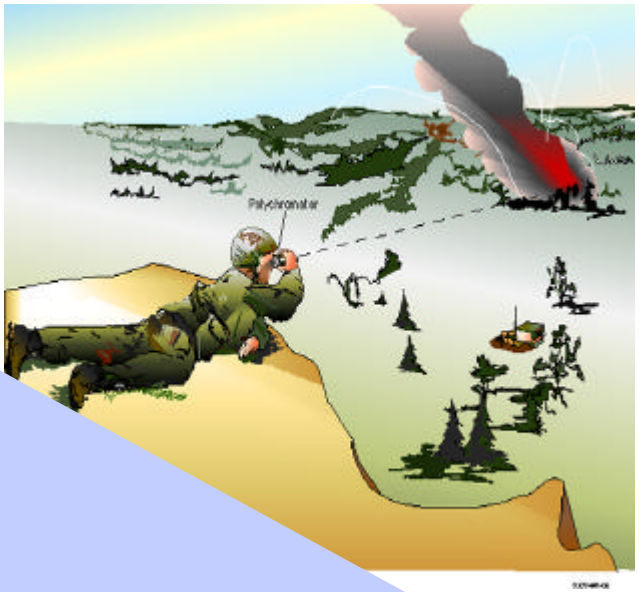
Micro resonant strain gage with over 10,000x sensitivity of metal foil strain gages. Nominal sensitivity 600Hz/µstrain. (UCB)

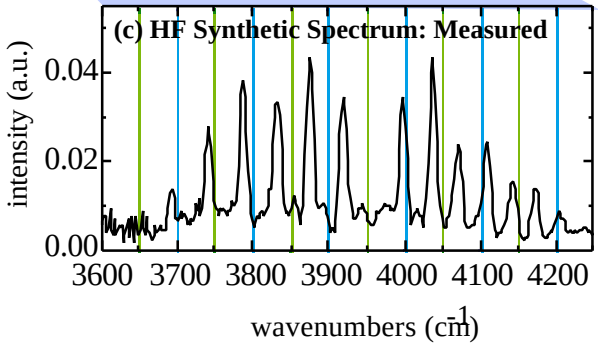
Standoff Chemical Sensing

MEMS Polychromator



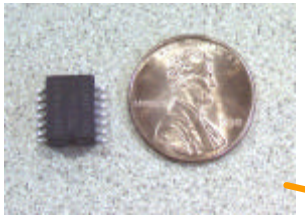
Honeywell Corp.



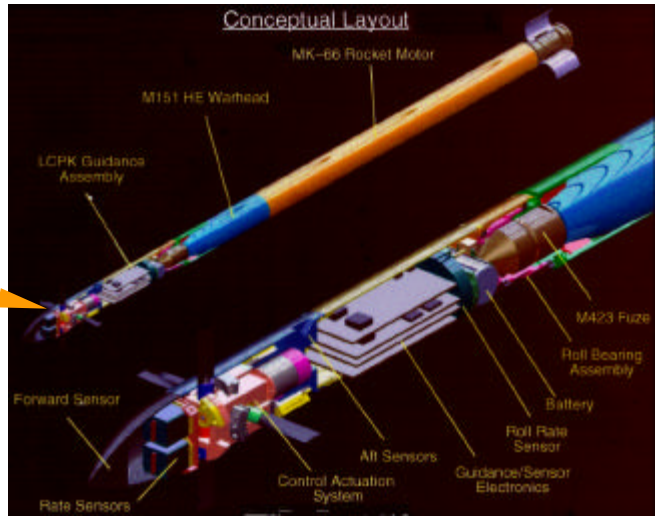


- **A new concept for a programmable, dark-field correlation spectrometer based on a MEMS diffraction grating.**
- **Leads to development of a miniature, programmable remote chemical detection system for field use.**

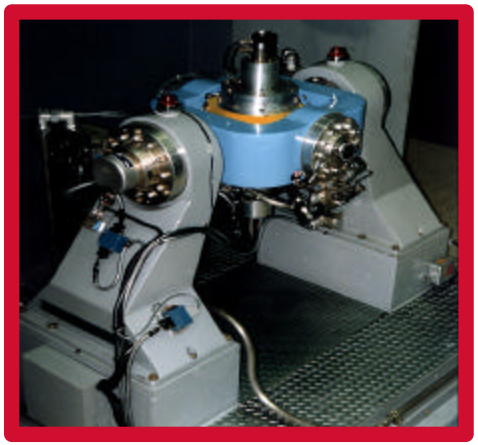
MEMS Sensor for Munitions



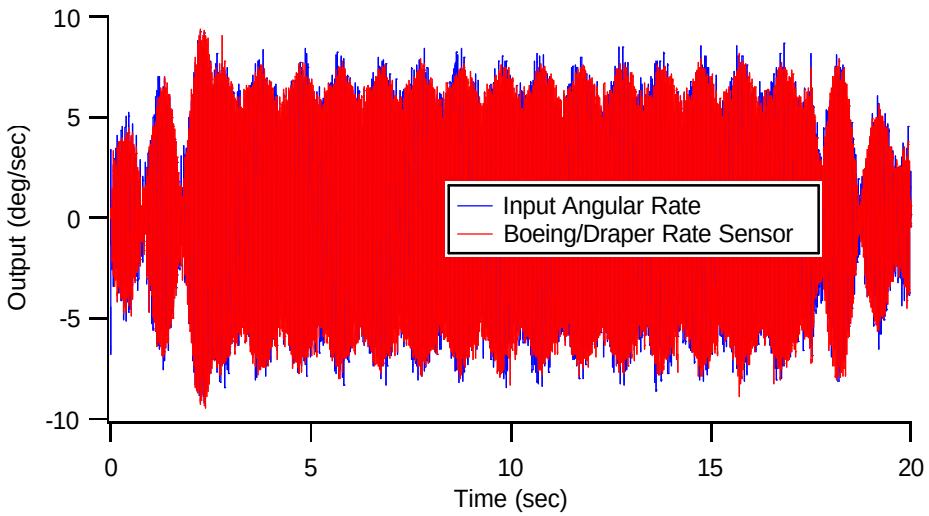
Rate Grade Inertial MEMS



Angular Rate Sensor Ground Tests



2.75” Rocket - Low Cost Precision Kill



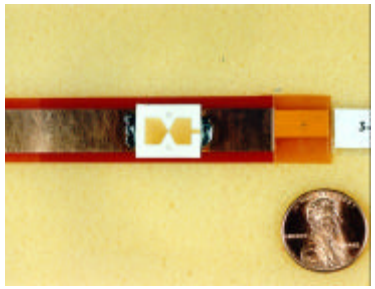
Comparison of ARL Flight Simulator and MEMS Tuning Fork Data

MTO
DARPA
Microsystems Technology Office

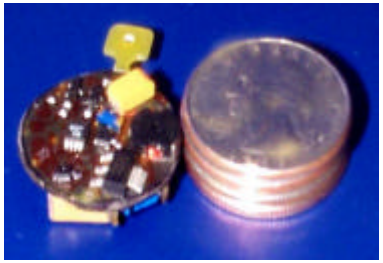
ARL
Weapons and Materials Research Directorate

MEMS Safe/Arm/Fuse for Torpedoes

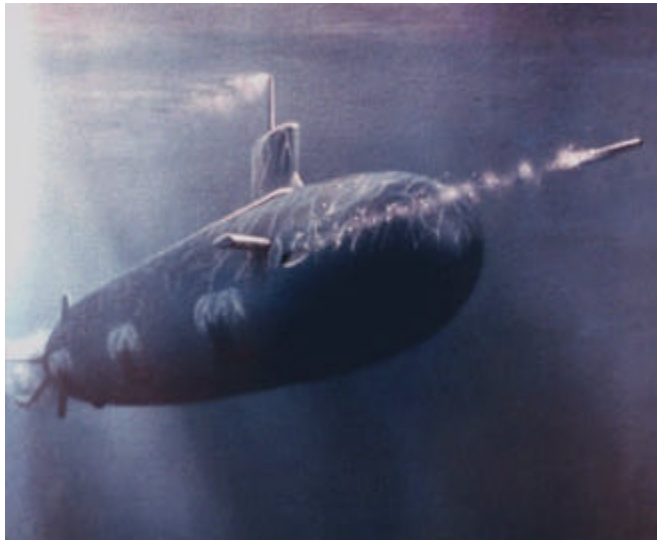
Inertial Measurement Unit
Rate Sensor

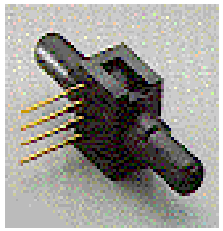


Slapper Detonator
(mounted on strip-line)

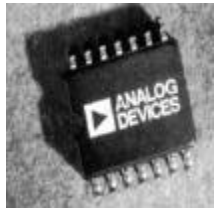


Slapper Fire-set
Fire-set and Optical Charging Circuit





Flow Sensor:
Pressure Differential



Impact Sensor

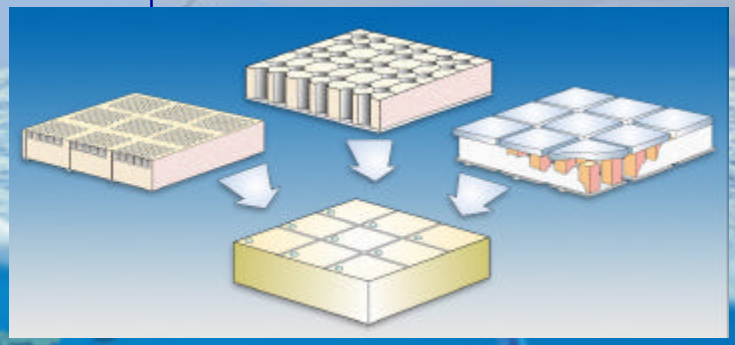
MEMS Exploder
7 cu in

MK 48 Exploder
118 cu in

MEMS technology enables:
- **17X reduction in volume &**
- **4X reduction in production cost**

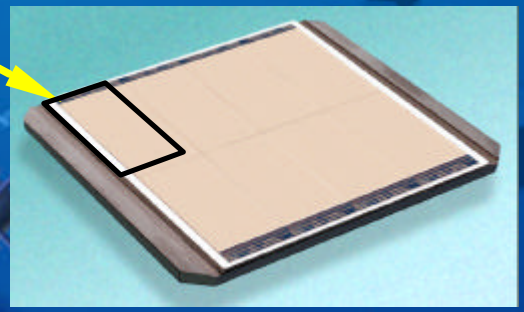
Sonoelectronics (ATO)

CRAFT LANDING ZONE (CLZ) | SURF ZONE (SZ) | VERY SHALLOW WATER (VSW) | SHALLOW WATER (SW) | BLUE WATER



3 Different MEMS Transducers Mate to a Single Transmit / Receive IC

- Short-range imaging (5-10 m)
- Good resolution even in turbid water
- Compact, stealthy, low-power, portable
- "Video camera" operation
- Image while steady / hovering



Transducer Hybrid Assembly Concept with Eight 32x64 Tiles

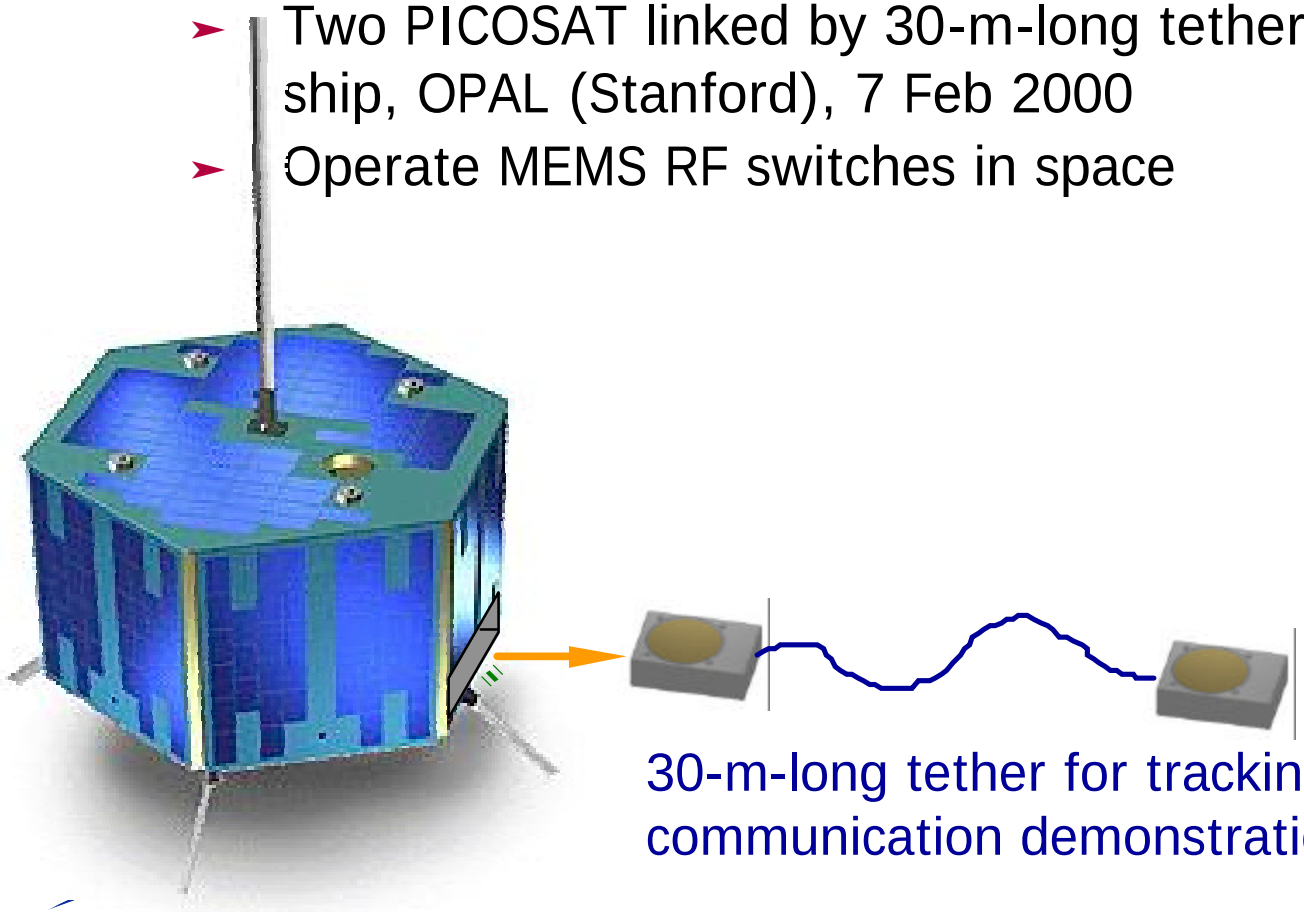
Image courtesy of Lockheed Martin

Pico Satellite Potential Applications

- Cooperative constellations
- Sparse aperture antennas
- Inspect and service missions
- Extremely agile launch-on-demand, short-term, survivable and robust communications and surveillance space systems

PicoSAT Aboard Stanford OPAL Satellite

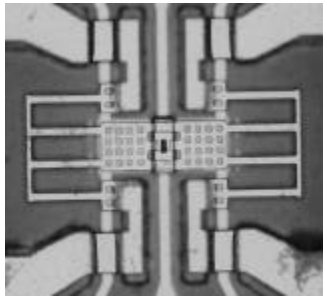
- First demonstration:
  - Launched by first flight of Minotaur 26 Jan 2000 (sponsored by Air Force and Missile System Center)
  - Two PICOSAT linked by 30-m-long tether jettisoned from a mother ship, OPAL (Stanford), 7 Feb 2000
  - Operate MEMS RF switches in space



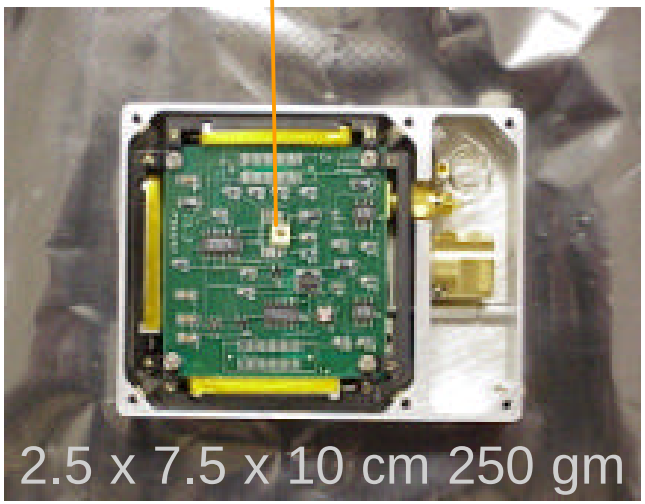
30-m-long tether for tracking & communication demonstration

MEMS in Pico Satellites

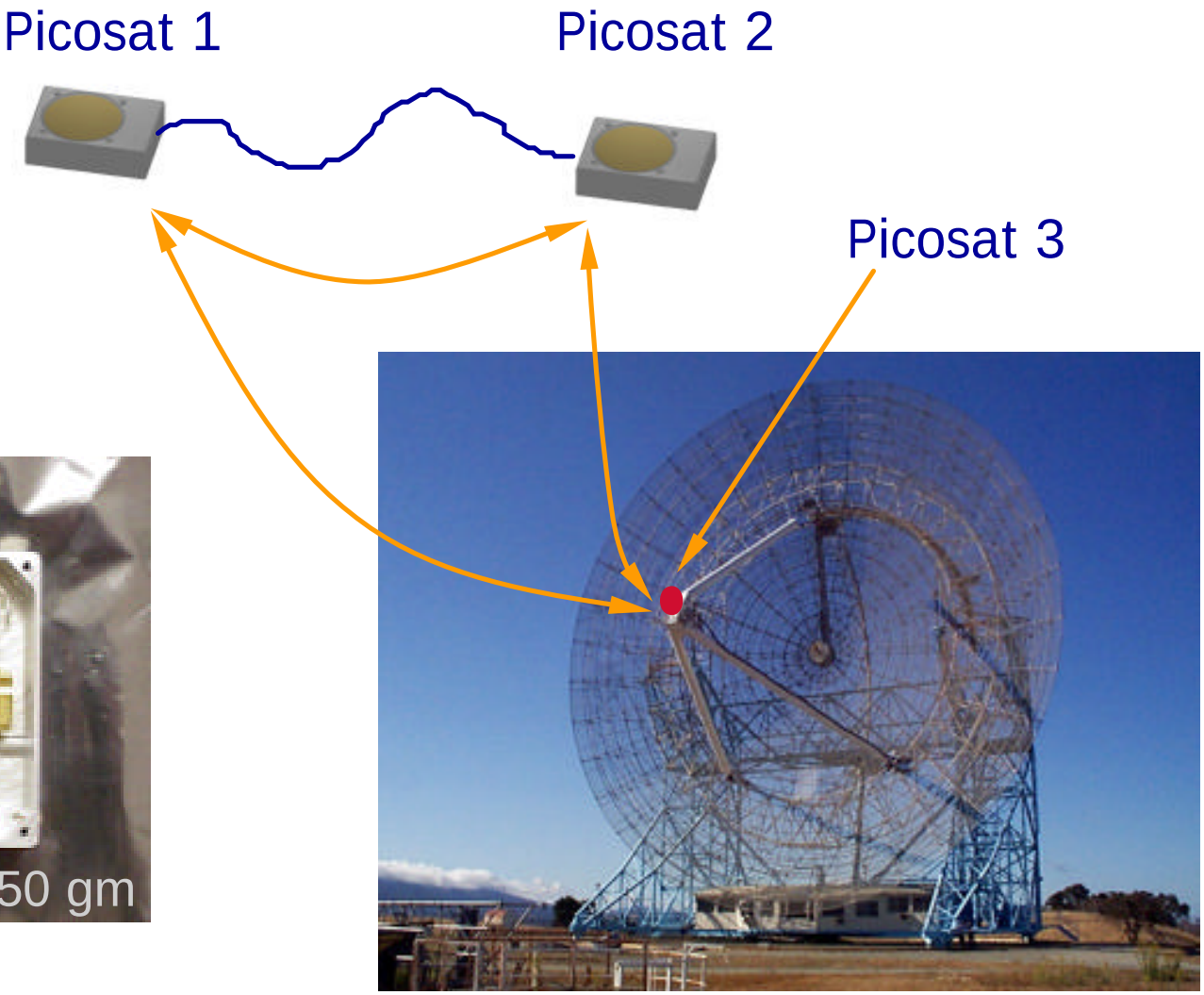
Pico Satellite Data Hopping Demo



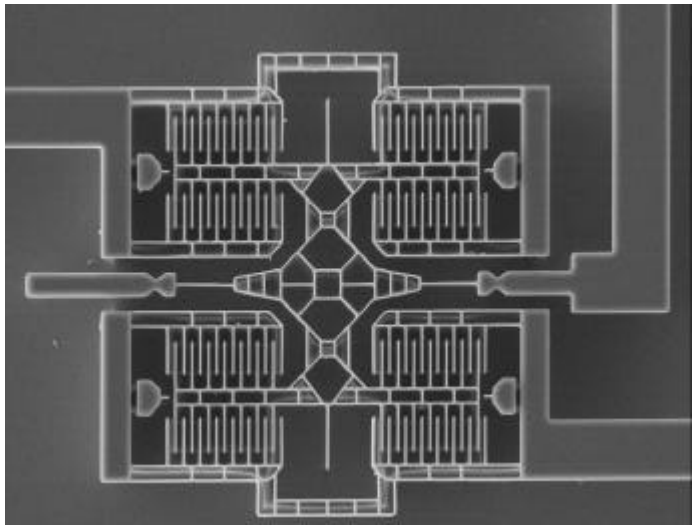
MEMS RF switch (Rockwell)



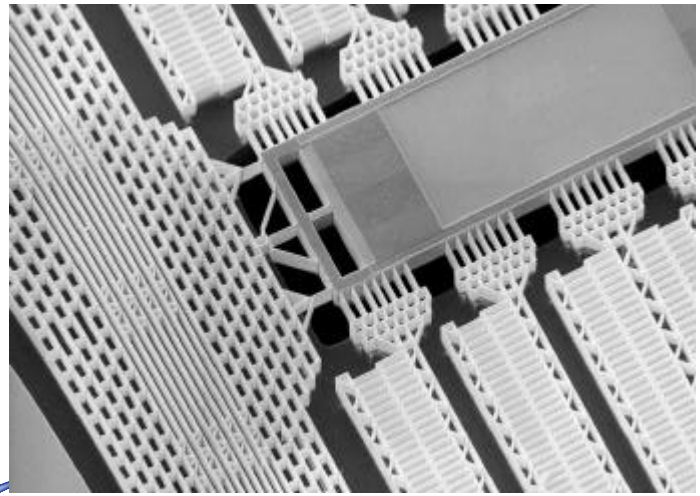
Pico Satellite (Aerospace Corp)

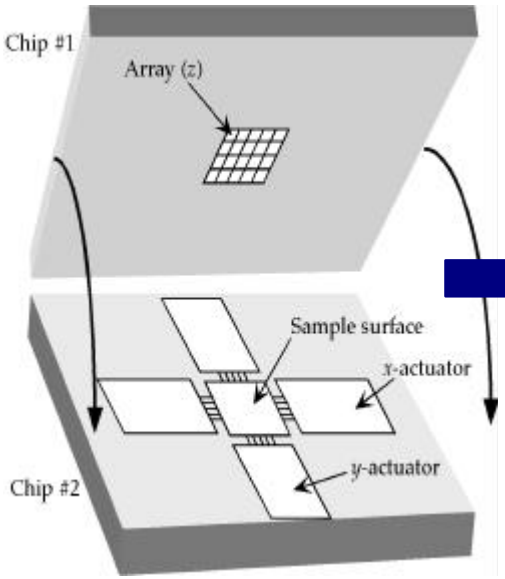


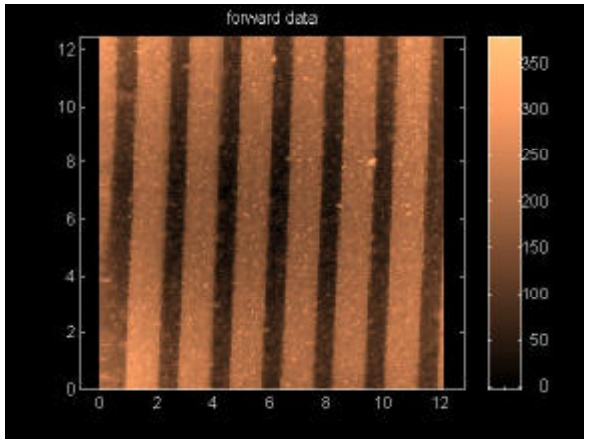
MEMS Actuators for Data Storage



Parallel atomic force imaging with MEMS to exceed densities of conventional magnetic and optical storage

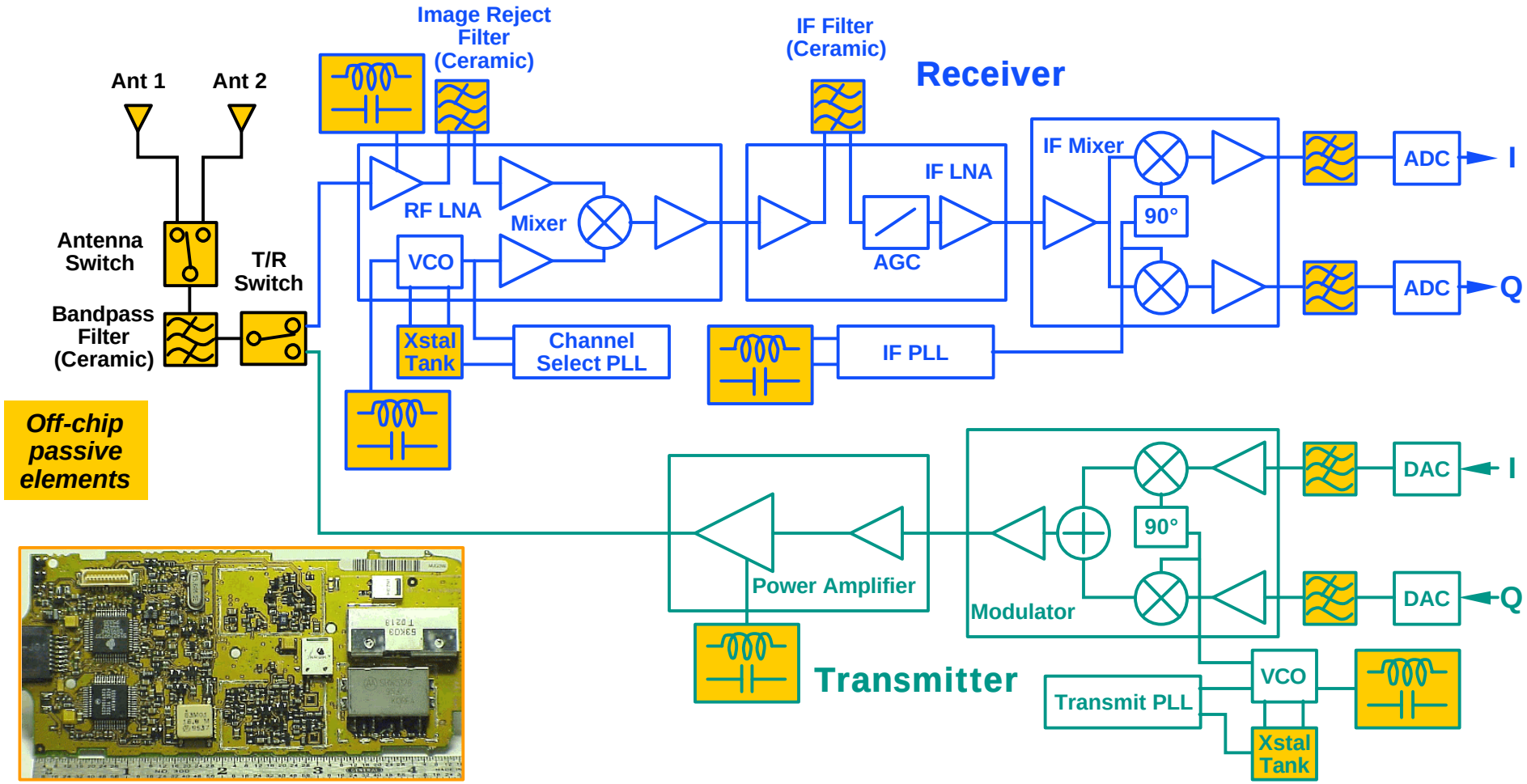






Areal density: 1-100 Gb/cm^2
Transfer Rates: 0.1-10 Mb/s
Size: 0.5 cm^3
Power consumption: <1W

MEMS-Replaceable Transceiver Components



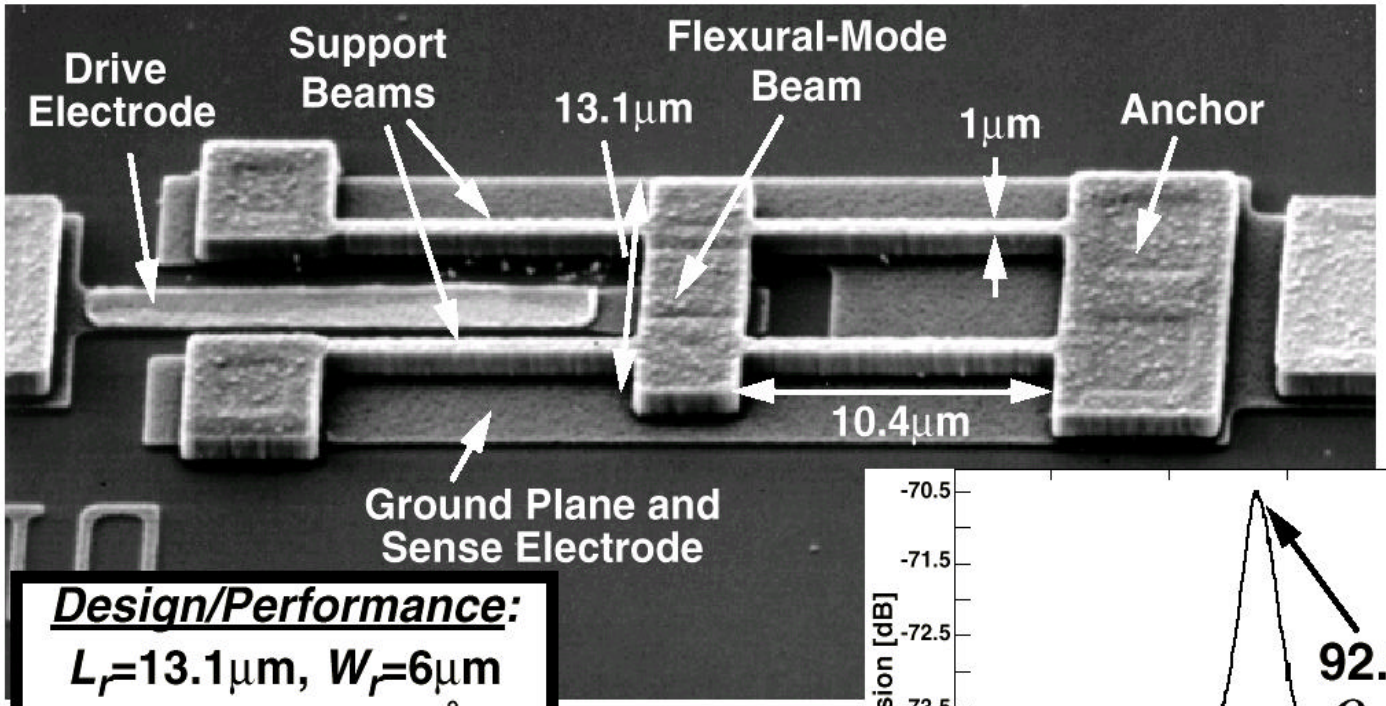
Current Cell Phone Board
Off-chip C & L = 80% of area

Current research:

✓ **Replace all off-chip passive elements with MEMS resonators & filters Þ chip-scale integration & improved performance**

92 MHz Free-Free Beam μ-Resonator

- Free-free beam μ-mechanical resonator with non-intrusive supports ➠ reduce anchor dissipation ➠ higher Q



Design/Performance:

L_r=13.1μm, W_r=6μm

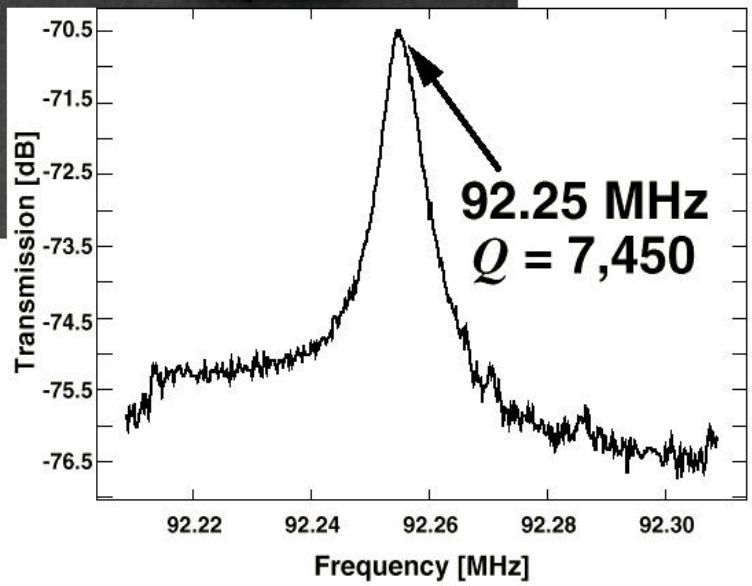
h=2μm, d=1000Å

V_P=28-76V, W_e=2.8μm

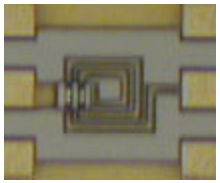
f_o~92.25MHz

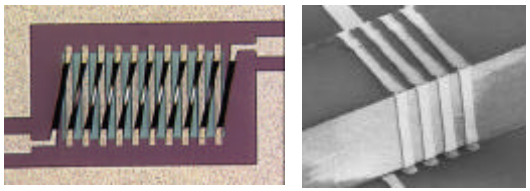
Q~7,450 @ 10mTorr

[Wang, Yu, Nguyen 1998]

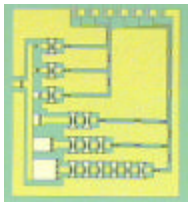


Tunable RF Filters for Multi-Band Communications

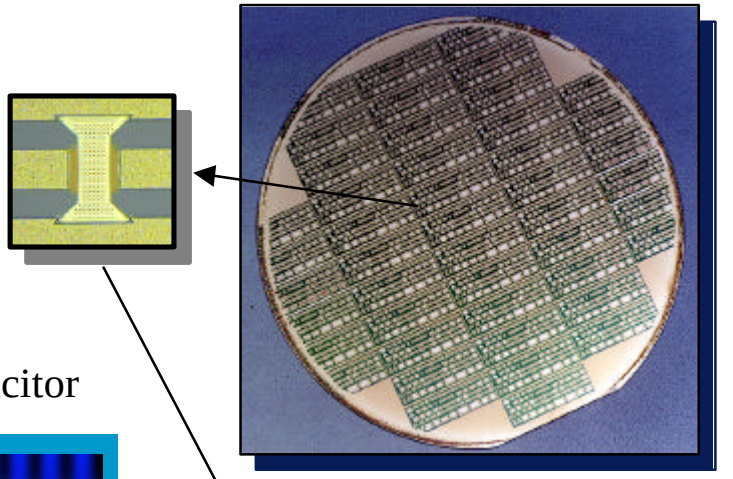




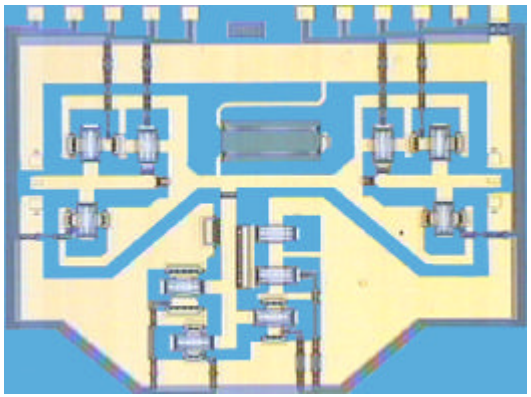
High-Q Inductors



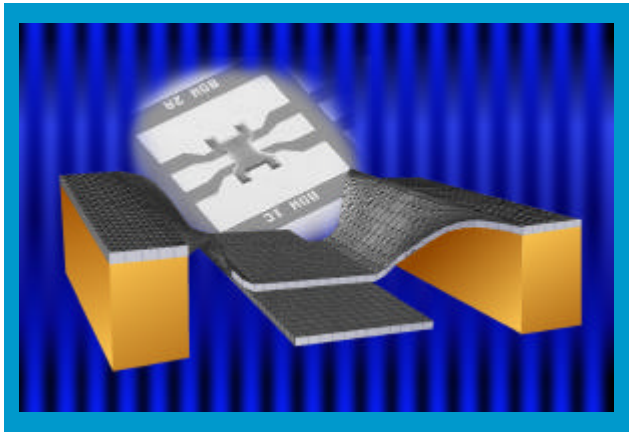
Variable 6 Bit MEMS Capacitor

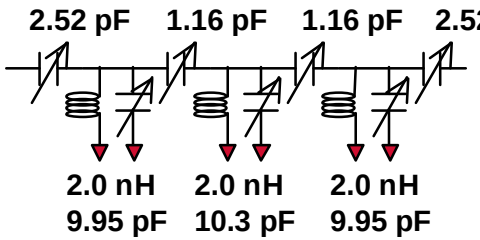


MEMS Variable Capacitors



MEMS Tunable Filter

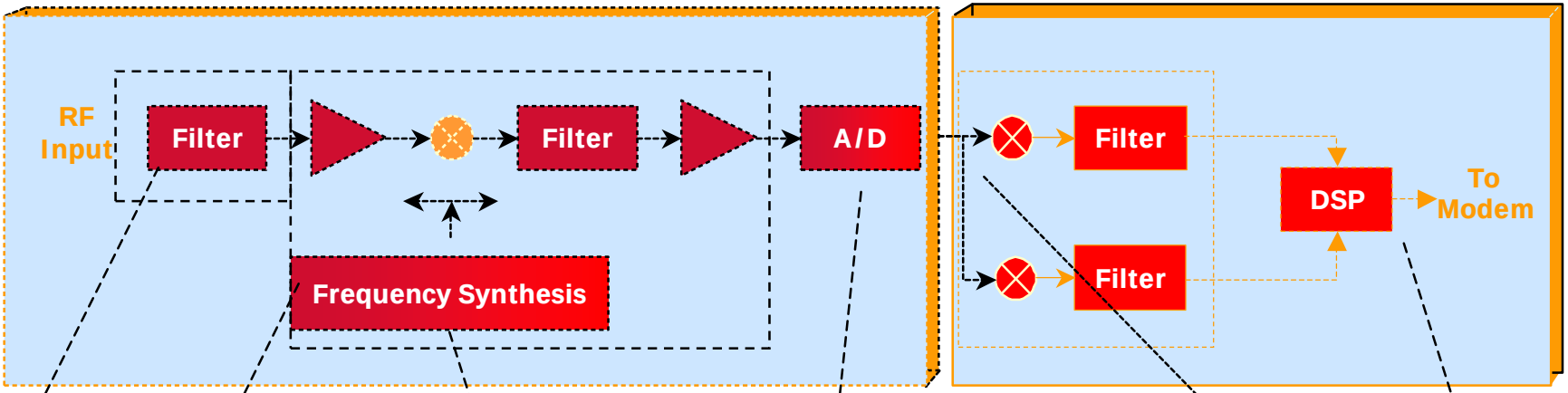


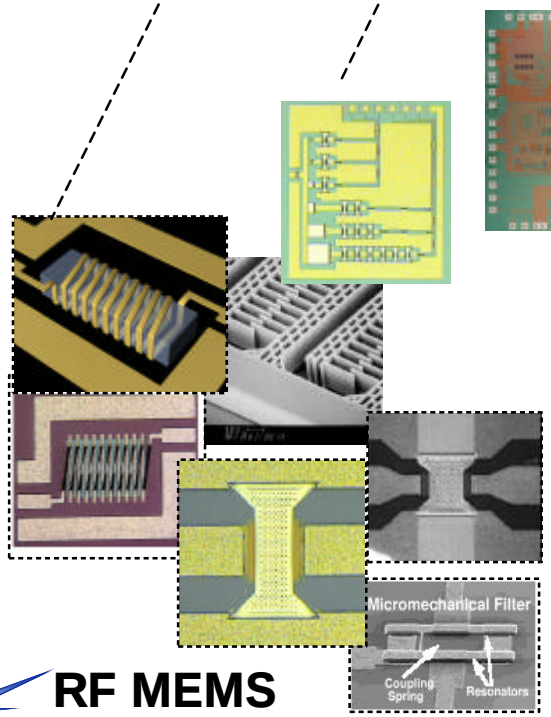


Tunable Filters

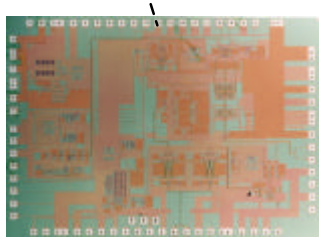
Advanced Digital Receiver (ATO)

Digital IF w/ Bandpass Sampling

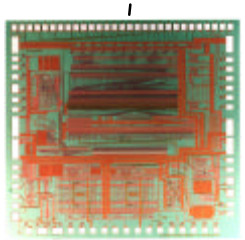




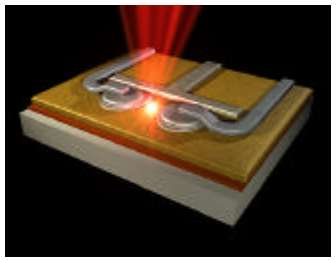
RF MEMS



SiGe ASIC



High Speed ADCs



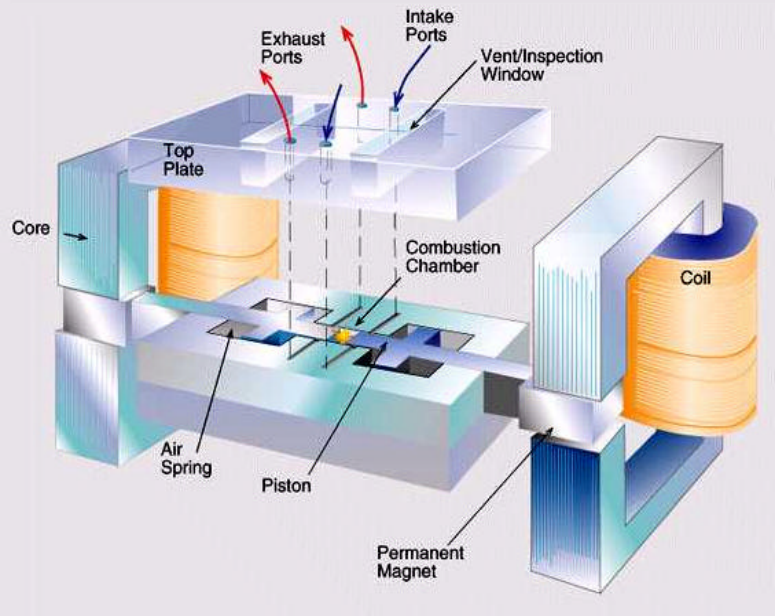
VCSEL Interconnect

C6x DSP

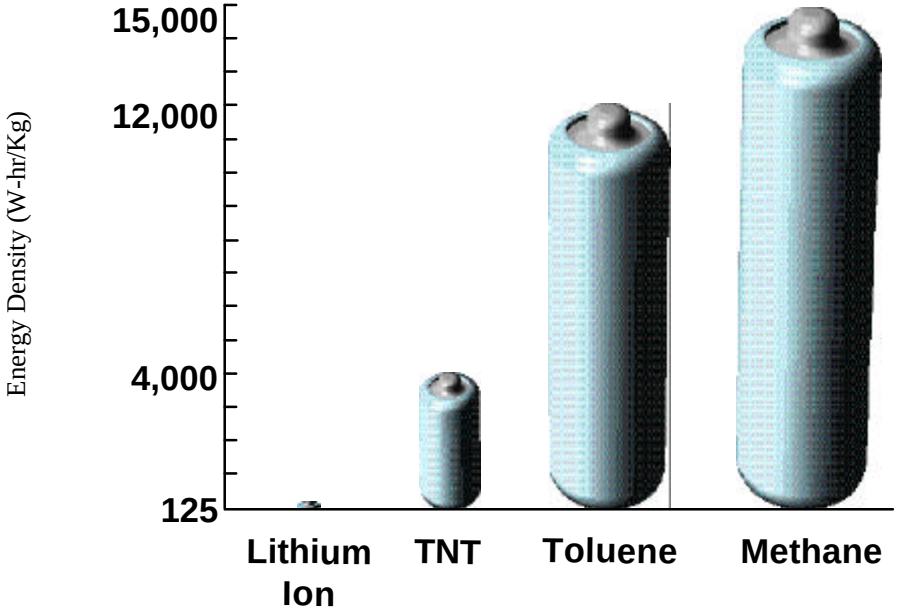
Outline

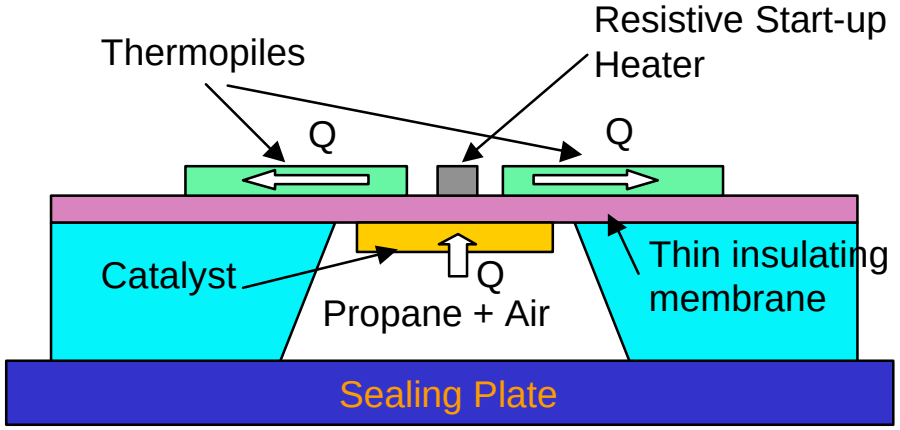
- Introduction
- Current Thrusts
- New Programs
  - MEMS Power Source
  - Harsh-environment MEMS
  - BioFlips
- Conclusion

High-Energy-Density MEMS Power



Honeywell Knock Engine Concept (New Start)

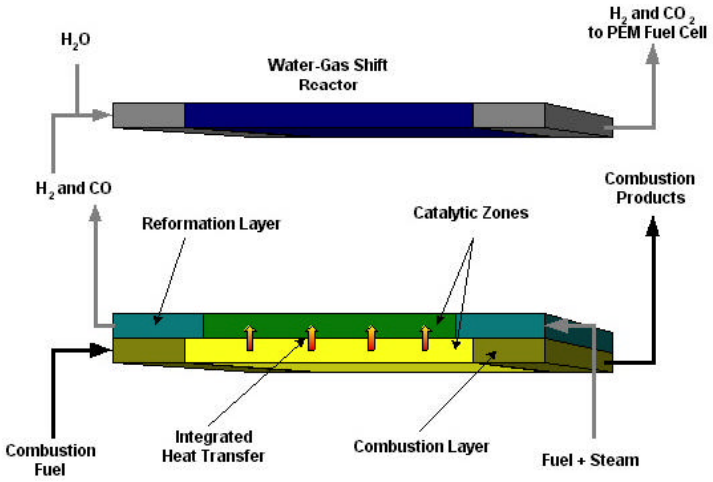




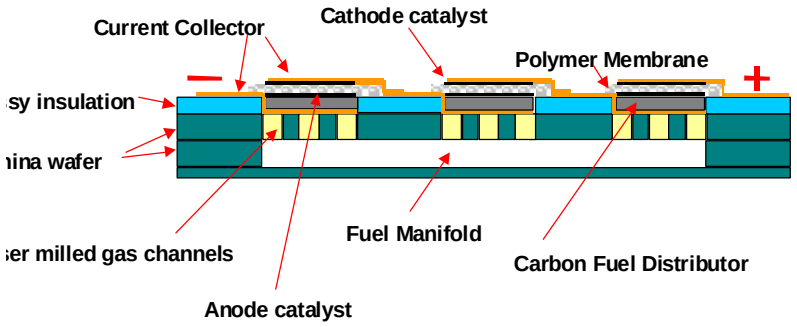
MIT Thermoelectric Generator Concept (New Start)

Integrated Fuel Cell and Fuel Processor for Microscale Power Generation (Battelle)

- Objectives
  - Demonstrate a 10 milliwatt fuel processor operating with clean liquid fuels (24 months)
  - Demonstrate a 10 milliwatt fuel cell (24 months)
  - Demonstrate a 50 milliwatt fuel processor operating with logistics fuels (36 months)

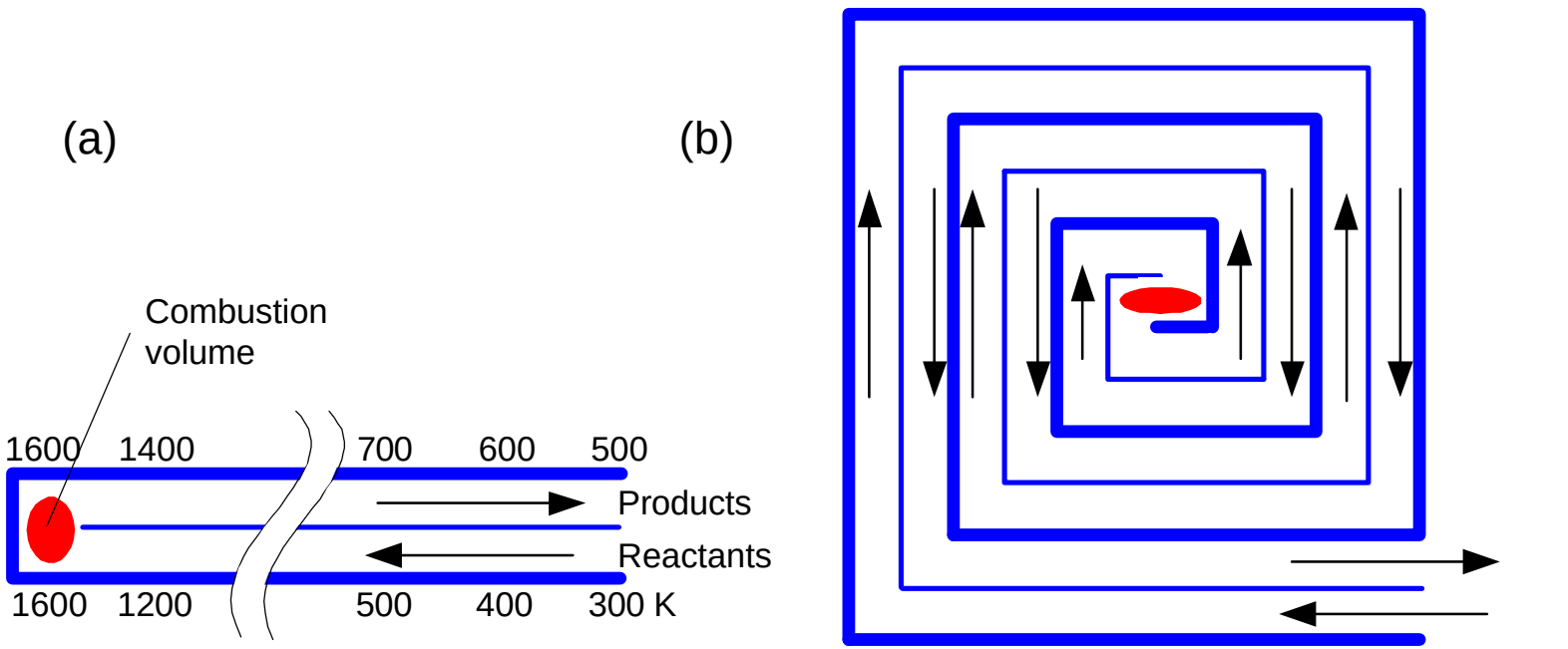


Concept – Fuel Processor

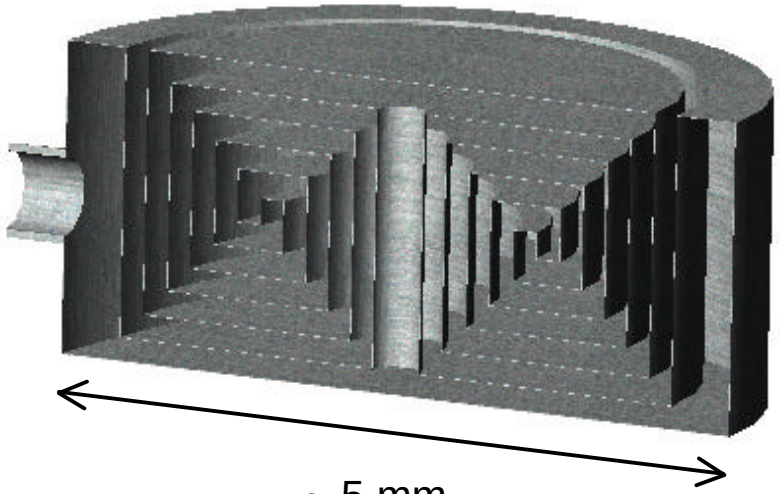


Concept – Fuel Cell

Swiss Roll Combustor (USC)



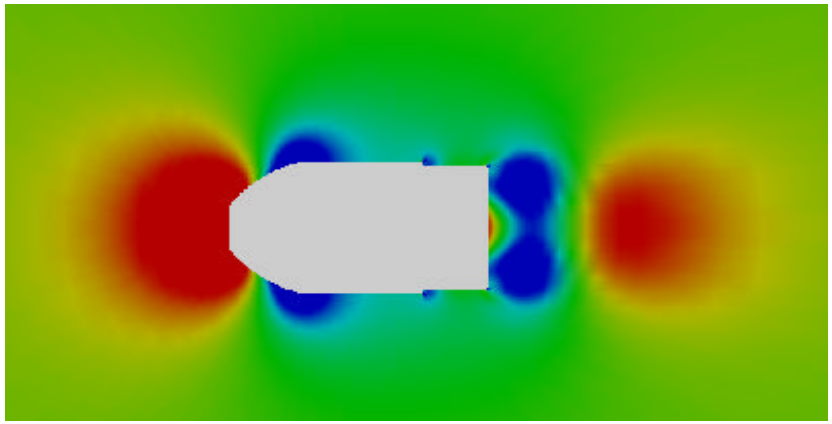
3-D toroidal Swiss roll microcombustor/generator



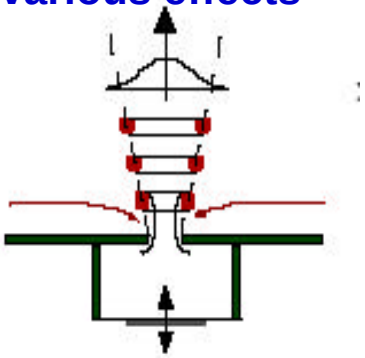
MEMS Flight Control for Projectiles

ARL Computational Fluid Dynamics Codes

- **Understand basic aerodynamic characteristics for flow control**
- **Investigate "where" jets could be placed for various effects**

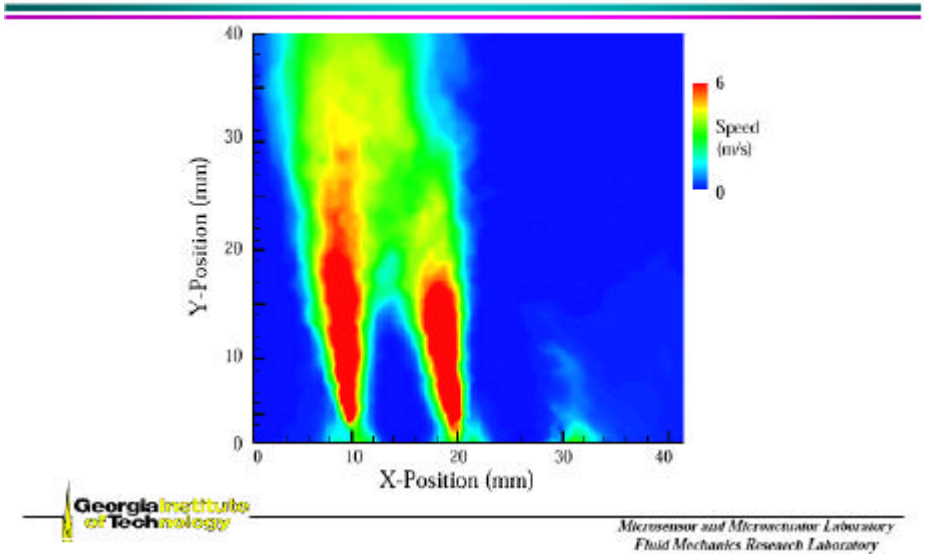


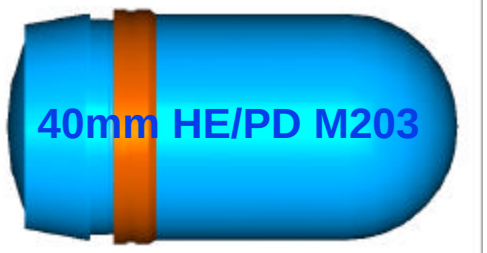
Pressure Contours
40mm Grenade, M = 0.25



Expanded View of Synthetic Jet from GaTech

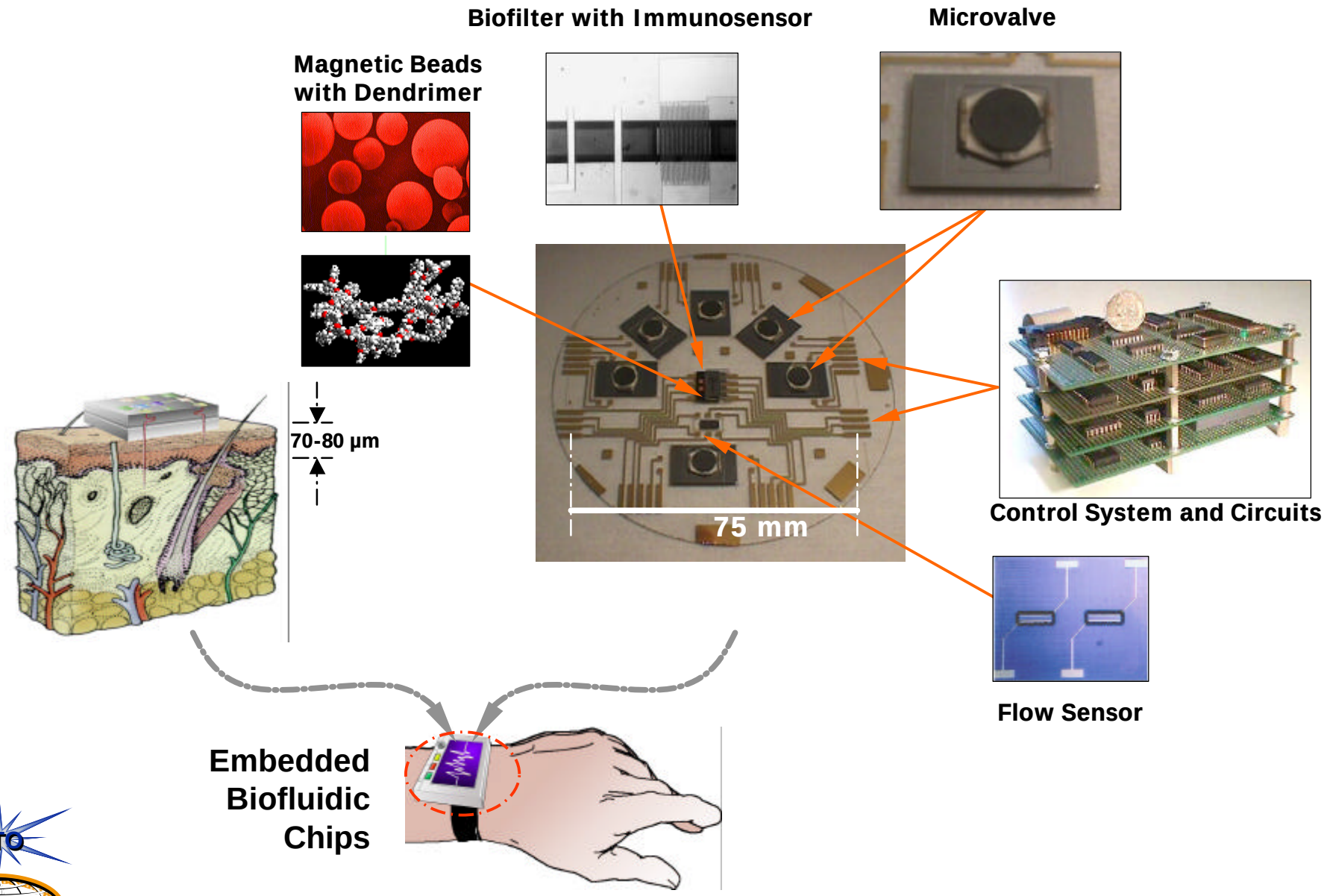
PIV Data of Modulated Microjet Array





Weapons and Materials Research Directorate

"BioFlips"– Integrated Microfluidic System for Bio-Chemical Assay



Outline

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MEMS Market and Industry

Technology Area	Typical Devices/ Applications	Companies	Market Baseline ($Millions)	Market 2003 (Est.) ($Millions)
Inertial Measurement	Accelerometers, Rate Sensors, Vibration Sensors	TI, Sarcos, Boeing, ADI, EG&G IC Sensors, AMMi, Motorola, Delco, Breed, Systron Donner, Honeywell, Allied Signals	$350-$540	$700-$1400
Microfluidics and Chemical Testing/ Processing	Gene Chip, Lab on Chip, Chemical Sensors, Flow Controllers, Micronozzles, Microvalves	Battelle, Sarnoff, Microcosm, ISSYS, Berkeley MicroInstruments, Redwood, TiNi Alloy, Affymetrix, EG&G IC Sensors, Motorola, Hewlett Packard, TI, Xerox, Canon, Epson	$400-$550	$3000-$4450
Optical MEMS (MOEMS)	Displays, Optical Switches, Adaptive Optics	Tanner, SDL, GE, Sarnoff, Northrop-Grumman, Westinghouse, Interscience, SRI, CoreTek, Lucent, Iridigm, Silicon Light Machines, TI, MEMS Optical, Honeywell	$25-$40	$450-$950
Pressure Measurement	Pressure Sensors for Automotive, Medical, and Industrial Applications	Goodyear, Delco, Motorola, Ford, EG&G IC Sensors, Lucas NovaSensor, Siemens, TI	$390-$760	$1100-$2150
RF Technology	RF switches, Filters, Capacitors, Inductors, Antennas, Phase Shifters, Scanned Apertures	Rockwell, Hughes, ADI, Raytheon, TI, Aether	(Essentially $0 as of 1998)	$40-$120
Other	Actuators, Microrelays, Humidity Sensors, Data Storage, Strain Sensors, Microsatellite Components	Boeing, Exponent, HP, Sarcos, Xerox, Aerospace, SRI, Hughes, AMMI, Lucas Novasensor, Sarnoff, ADI, EG&G IC Sensors, CP Clare, Siemens, ISSYS, Honeywell, Northrop Grumman, IBM, Kionix, TRW	$510-$1050	$1230-$2470

Companies currently under contract. Companies with past contracts.

The Future

- Continue existing commitment
  - Maturing projects
  - New thrust: Micro Power Generation
- Emphasize transition
  - Into DoD systems
  - Into industry
- Establish new programs
  - Programs enabled by MEMS